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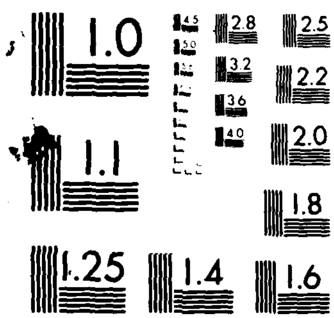

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GREAT LAKES-ST.LAWRENCE SEAWAY SIMULATION STUDIES

Volume 4

NETSIM II AND PROSIM: A WATERWAY SIMULATION PACKAGE

Joseph L. Carroll
Department of Business Logistics

Srikanth Rao
Department of Management

Hoyt G. Wilson
Department of Business Logistics

Final Report

Contract No. DACW23-72-C-0066

December 1973

PENNSYLVANIA TRANSPORTATION
AND TRAFFIC SAFETY CENTER

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A111 940	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Great Lakes-St. Lawrence Seaway Simulation Studies. V.4 NETSIM II and PROSIM: A Waterway Simulation Package.		5. TYPE OF REPORT & PERIOD COVERED Final Report July 1972 thru August 1973
		6. PERFORMING ORG. REPORT NUMBER TTSC 7319
7. AUTHOR(s) Joseph L. Carroll, Srikanth Rao, and Hoyt G. Wilson		8. CONTRACT OR GRANT NUMBER(s) DACW23 72C 0066
9. PERFORMING ORGANIZATION NAME AND ADDRESS Pennsylvania. State University. Transportation and Traffic Safety Center.		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Engineer Division, North Central. Planning Division. Economics Branch.		12. REPORT DATE December, 1973
		13. NUMBER OF PAGES 205 p.
14. MONITORING AGENCY NAME & ADDRESS(If different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release. Distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Approved for public release. Distribution unlimited.

18. SUPPLEMENTARY NOTES

Library of Congress number assigned by controlling office:
TA1145 P412ttsc No.7319
Series title: Great Lakes Simulation Studies. Series title varies.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

1. TRANSPORTATION MODELS 2. COMPUTERIZED SIMULATION 3. WATERWAY TRANSPORTATION 4. GREAT LAKES 5. ST. LAWRENCE SEAWAY 6. NETSIM II 7. PROSIM

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In developing a computer model for the simulation of the Great Lakes and St. Lawrence Seaway navigation system, this volume explains the NETSIM II (a general network simulator) program's input, logic and operations including tests and a user manual. A sample problem is attached. It also explains the PROSIM (a simulation processor for NETSIM II) program, input, operations, and output tables with its user manual. Other programs treated briefly are: a vessel generation program, a commodity arrival generation program, an itinerary program, and an EDB simulation program.

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U.S. Army Corps of Engineers

North Central Division

Pennsylvania Transportation and Traffic Safety Center

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December 1973

ABSTRACT

This report presents a detailed description of a computer simulation package designed for the Great Lakes-St. Lawrence Seaway navigation system. The discussion is divided into three parts corresponding to the major components of the simulation package. Part I covers NETSIM II, the simulation program itself. Part II covers PROSIM, the statistical report generator for NETSIM II. Each of these programs is written in SIMSCRIPT and each is composed largely of subroutines which carry out processing for the various kinds of navigation facilities. This modular structure greatly simplifies the task of program modification. Part III describes four FORTRAN programs which have been provided to facilitate data preparation for NETSIM II. Detailed user manuals are included for all programs in the package.

The model is addressed to the task of analyzing the performance of a waterway system under various structural and nonstructural improvements. The analysis is in terms of delays, congestion and utilization. The major feature of the model is its ability to simulate traffic flows which result from a given pattern of transport demand (commodity movements).

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FOREWORD

The work described in this report was performed by The Pennsylvania Transportation and Traffic Safety Center (PTTSC) at the Pennsylvania State University for the U. S. Army Corps of Engineers, North Central Division, under contract number DACW-23-72-C-0066. The contract period is from July 1, 1972 to August 31, 1973.

This report is the fourth in a series of four volumes documenting the development and application of a computer model for the simulation of the Great Lakes and St. Lawrence Seaway navigation system. Other titles in this series are as follows:

Volume 1	NETSIM: A General Network Simulator
Volume 2	Lake Erie-Lake Ontario Navigation: A Simulation Study of Alternative Subsystems
Volume 3	Summary Report

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ACKNOWLEDGEMENTS

Development of the programs reported here was made possible by the support and cooperation of the Corps of Engineers. Chief representative of the Corps throughout the study was Robert A. MacLauchlin, Chief, Economics Branch, North Central Division. Acknowledgement is also made of the assistance provided by the Economists, Buffalo District.

Representatives of St. Lawrence Seaway Authority also provided valuable inputs to the research. Particular thanks are due to Malcolm S. Campbell, Regional Direction, Western Region and Henry L. Koski, Traffic Control Officer and Erich Ahermae, Operations.

Financial support for this research was provided by the Corps of Engineers, and also by The Pennsylvania State University, primarily through the provision of computer time for exploratory programming efforts.

The authors would like to take this opportunity to thank each member of the project team listed in the Foreword for their efforts in bringing this study to a successful conclusion. Thanks are also due to Mrs. Ru-Fen Chow of PTTSC for her editorial assistance.

The opinions, findings, and conclusions expressed in this publication are those of the authors, and not necessarily those of the Corps of Engineers nor The Pennsylvania State University.

PART I

NETSIM II : A NETWORK SIMULATOR

CHAPTER 1. INTRODUCTION

A. GREAT LAKES-ST. LAWRENCE WATERWAY SYSTEM

In June of 1972, the Army Corps of Engineers, North Central Division, entered into a contract with the Pennsylvania Transportation and Traffic Safety Center (PTTSC) for the development of a simulation model that would facilitate a systematic analysis of the capacity of the Great Lakes-St. Lawrence Waterway System (GL-SLS). The development of this simulation model has been carried out in three phases:

1. development of a Lake Erie-Lake Ontario (LE-LO) Navigation Simulation model;
2. application of the LE-LO model to simulation studies of the Welland Canal and proposed alternatives to the Welland;
3. revision of the LE-LO model to include the capabilities needed for comprehensive GL-SLS system simulations.

The simulation program (NETSIM II) described in this report represents the completion of the third phase. The efforts in upgrading the LE-LO model have been directed specifically at creating a GL-SLS simulation model. That is, flexibility was maintained wherever possible, but overall, the program has clearly been tailored to the special structure of the GL-SLS.

The Great Lakes-St. Lawrence Waterway System consists of the St. Lawrence River, the five Great Lakes (Lakes Superior, Michigan, Huron, Erie, and Ontario), Lake St. Clair and several connecting channels, including the Welland Canal. Since the system is linked to the Atlantic Ocean by the St. Lawrence River, it serves not only for intrasystem commodity movements, but for trade with saltwater ports outside the system as well.

The lakes are relatively uncongested and allow free movement of vessels on them. Width and depth of some of the reaches, however, along with traffic regulations, provide significant constraints to vessel speeds. Further, the locks in the St. Lawrence River, the Welland Canal and at Sault Ste. Marie are potentially serious impediments to traffic flows.

B. THE NETSIM II SIMULATION PROGRAM

Historically, development of NETSIM II dates back to the use of computerized simulation models on the inland waterways. The circumstances leading to their development and the results of that research are reported in a six-volume technical report entitled Waterway Systems Simulation [1, 2, 3, 4, 5, 6]. The groundwork for the current model was laid in Volume V of this series, entitled Simulation of Multiple Channel Deep Draft Navigation Systems [5].

In NETSIM II, the sophistication of the locking routines in particular is in large part due to the earlier research. In fact, the lock routines in NETSIM II have been simplified somewhat from those of its predecessor (the LE-LO model), as it was felt that such a detailed micro model of the locks was unnecessary in this more comprehensive system simulation.

The experience data bank (EDB) concept used in NETSIM II was developed in the Multiple Channel Deep Draft Navigation Systems study. In this approach, a run of the simulation model itself produces data from which expected transit times through a route segment can be estimated based upon system conditions. The estimation equation is then used in subsequent runs as the criterion for a vessel's choice between parallel route segments. That is, whenever a vessel is confronted with a choice between two parallel routes to the same destination, the alternative which offers the lower expected transit time will be chosen.

The primary capability which has been added to the LE-LO model in order to give NETSIM II the capacity for systems simulation is a vessel scheduling mechanism. Whereas the LE-LO model required a schedule of vessel movements as input data, NETSIM II develops these schedules dynamically based upon the requirements for commodity transport. This dynamic scheduling capability allows study of such matters as vessel fleet requirements, efficiency of various scheduling rules and implications of hypothetical changes in the mix of commodity flows.

NETSIM II has retained flexibility in two respects. First, it is written in a powerful language--SIMSCRIPT--with its logic modularized to a great degree. This means that modifications to one aspect of the model (e.g., calculation of transit times across lakes) can often be made by altering only one or two subroutines and leaving the rest of the program untouched. Second, the model can simulate networks of virtually any reasonable size and configuration. This means that the program can accommodate the entire GL-SLS or any part of it. Also, the number of ports, locks, etc., to be included may be changed at will. The only constraint on system size is the amount of computer core memory and run time available. Requirements for auxiliary input/output devices are modest.

The primary output of NETSIM II is an event log, which consists of a separate detail record for every event of interest which occurs during the course of the simulation. Here, by "event" is meant such status changes as "vessel enters berth", "vessel exits lock chamber", "vessel enters queue for berth" or "vessel departs reach". These data in their raw form are rather incomprehensible, so a separate SIMSCRIPT program, PROSIM, has been provided to process the event log data and produce meaningful reports for the user.

In addition to NETSIM II and PROSIM, the simulation package includes a number of auxiliary programs for input data preparation. These facilitate such tasks as preparation of vessel fleet data and arrivals of commodities (overland) into ports. Although they are quite independent of the NETSIM-PROSIM model, the auxiliary programs have been written in such a way as to coordinate directly with the use of the model.

The remainder of Part I of this report describes NETSIM II in detail. The following sections deal with program input requirements, program logic, program outputs and, finally, testing and calibration. Appendix A is a NETSIM II user manual and Appendix B contains an example problem.

CHAPTER 2. INPUT DATA

This chapter describes the classes of input data required by NETSIM II. The description includes enumeration of all major categories of input data and some discussion of their use within the program. Detailed card format specifications may be found in Appendix A, and Appendix B provides a listing of input data for an example problem.

The input to NETSIM II is made up of the following basic data groups (illustrated in Figure 2-1) listed in sequential order as they would be read in by the program:

(1) run parameters;

(2) description of the navigation facilities;

(3) description of the navigation network;

(4) commodity arrival list at ports;

(5) vessel fleet data;

(6) itineraries for saltwater vessels.

Each of these classes is treated in the following sections.

A. RUN PARAMETERS

This class of data includes the following items:

(1) length of the season to be simulated in minutes;

(2) run options;

(3) input-output devices;

(4) system size parameters;

(5) vessel classification parameters.

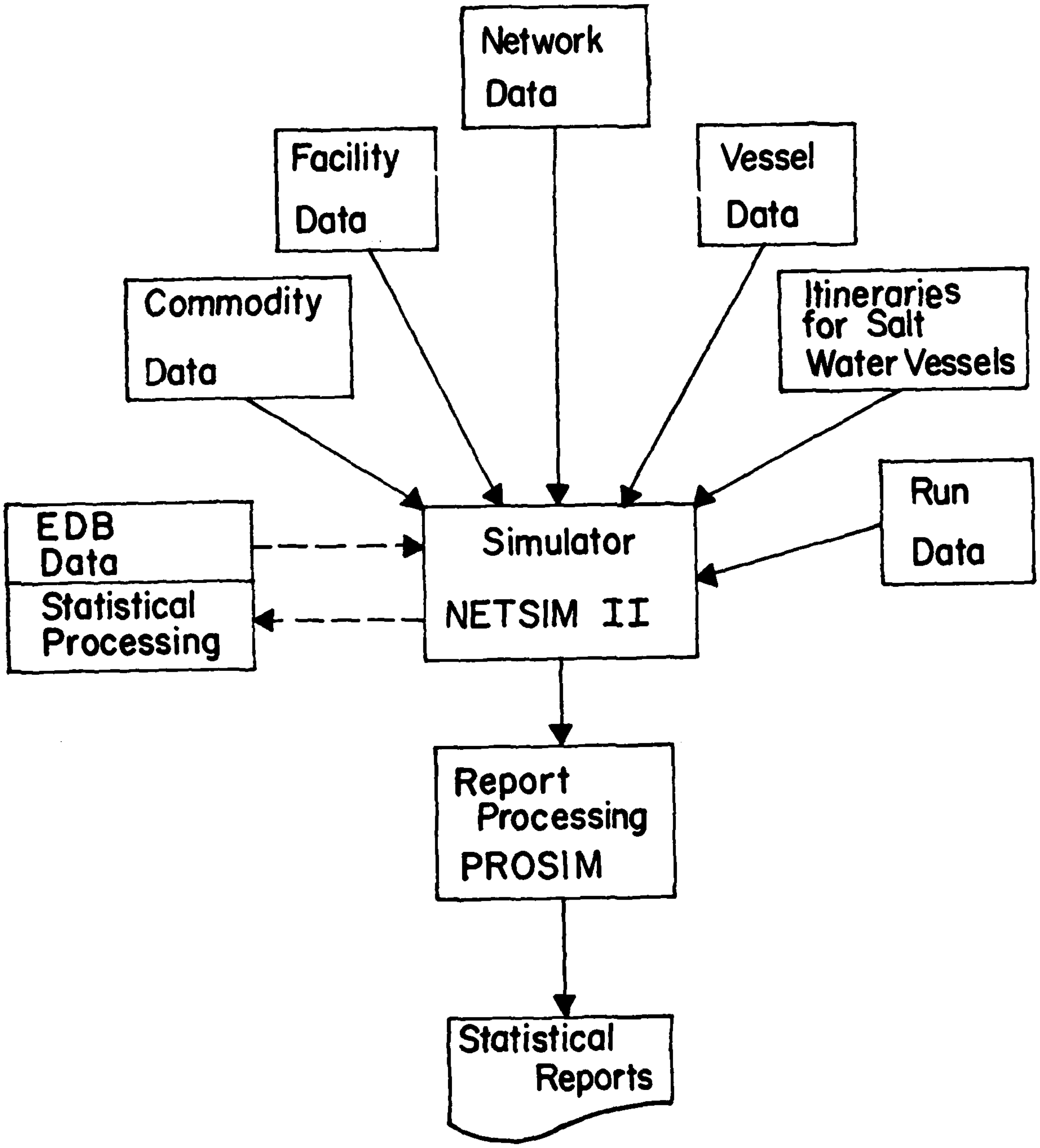

Figure 2-1. System Structure

Item 1 controls the total simulation run time and must be large enough to provide the user with a steady state simulation for the desired period. At the beginning of the simulation, the waterway system is allowed to start in an empty condition and a finite amount of time, referred to as the warm-up or transient time, is usually necessary for the system to reach steady state operation. So if it is desired to simulate a period of 30 days with a warm-up time of 4 days, the simulation run time T should be set at

$$T = 1440 \times 34$$

where the warm-up time has been added to the desired simulation period.

Item 2 specifies run type options. These include options for an experience Data Bank (EDB) run, use of the service look-ahead feature and a code for the existence of parallel route options in the waterway network.[1]

Item 4 allows the program to set up its entity set structures by defining the number of ports, locks, reaches, lakes, nodes and commodity types in the system. Certain other parameters, used mainly as pointers in the program are also included under this category.

Item 5 provides length and horsepower delineations for vessel classifications. These data are used in the program to adjust some average vessel processing times by vessel attributes.

B. DESCRIPTION OF THE NAVIGATION FACILITIES

This class of data provides descriptions of ports, lakes, reaches and locks in sequential order as required by the program.

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[1] These features are fully described in the next chapter.

1. Ports

A port is defined as a navigation facility on the waterway at which vessels may discharge and/or receive all or part of their cargoes. Due to their unique position as areas of transaction where the supply and demand of transportable commodities and transport equipment units interact, presumably towards some equilibrium to be determined during the simulation, ports are accorded a distinct treatment in NETSIM II. Specifically, the port routines contain the logic for dynamic vessel scheduling which assigns a vessel to its next destination based on the current location of the vessel in the system, the cargo carrying capabilities of the vessel, the cargo inventories and requirements at ports, and the proportion of empty movements on a particular route.

In accordance with the special treatment given to ports, the data needs are also more complex. The port data must include physical description by means of a port identification number, depth, and the number of berths available for loading and unloading cargo for each of four cargo types: general cargo, liquid bulk, dry bulk excluding grain, and grain. Also for each cargo type, the average loading and unloading rates and the standard deviations must be given. For each commodity type[2], the probability of empty backhaul occurrences is required.

A certain minimum amount of cargo must be available to qualify for loading onto a vessel. This minimum cargo level for general, dry bulk and liquid bulk cargo must be specified. If no minimum load is available at a port, inquiry can be made at one or more nearby ports to determine whether

---

[2] Note the distinction between commodity type and cargo types. There are only four cargo types in NETSIM II as noted above. Within the dry bulk cargo type, however, there may be distinct commodities.

a suitable cargo is available there. These nearby ports must be specified for each port. The user can also specify the maximum queue levels of vessels waiting to be assigned a cargo at any port before arriving vessels are sent back to their origins empty after being unloaded.

The port data also include a vessel loading factor which serves as a calibration factor, commodity arrival rates referred to as cargo influx rates in the program and used in the dynamic scheduling procedures, and finally a lower bound for port turnaround time, i.e., the minimum time to enter and exit the port.

In summary, the port data consist of the following items:

(1) vessel loading factor;

(2) minimum cargo levels;

(3) port identification;

(4) lower bound for port turnaround time;

(5) cargo influx rates;

(6) depth;

(7) nearby ports;

(8) unloading rates;

(9) loading rates;

(10) standard deviations for port turnaround time;

(11) cargo queue limits;

(12) number of berths available;

(13) probabilities of empty backhaul.

Items 4, 8, 9 and 10 are used in the calculation of port turnaround times.

2. Lakes

This class of data includes the following items:

(1) Physical description

(a) lake identification;

(b) number of nodes on the lake;

(c) code to indicate presence of parallel routes.

(2) Intralake travel table - an origin-destination (O-D) travel time matrix for all nodes on the lake.

As an alternative to the travel table, the user is allowed to specify the use of a theoretical distribution.

3. Reaches

This class of data includes the following items:

(1) Physical description

(a) reach identification;

(b) reach length;

(c) code to indicate whether passing is permitted;

(d) code to indicate presence of parallel routes;

(e) code to indicate theoretical or empirical transit time distribution;

(f) upstream node;

(g) downstream node.

(2) Transit time distribution - either theoretical or empirical.

(3) Expected transit time (ETT) function for each direction of travel if there are parallel routes (as indicated in Item 1d).

The ETT functions are not supplied for an EDB run.

4. Locks

The lock data consist of four main segments: physical description, locking time frequency distributions, adjustment factors for these distributions, and ETT functions.

Physical description of locks consists of the following items:

(1) lock identification;

(2) upstream node;

(3) downstream node;

(4) maximum vessel length accommodated in lock;

(5) code to indicate presence of parallel routes;

(6) codes to indicate theoretical or empirical locking time distributions.

For simulation purposes, the locking operation in NETSIM II is broken into five segments as shown in Figure 2-2[3]. Each of these segments requires either theoretical or empirical probability distributions.

The third category of lock data consists of adjustment factors for each of the five locking segments. These factors are used in NETSIM II to modify the distribution sampled value by vessel attributes. The exact modification performed within the program is dependent on the vessel classification parameters.

The final item under lock data consists of an ETT function for each direction of travel. These functions are only provided if a lock is part of a parallel route set and they are then used in the program's channel choice mechanism. The ETT functions are not provided for an EDB run.

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[3] In NETSIM I, the locking operation consists of nine distinct elements (see Ref. [1]). The higher degree of aggregation in NETSIM II accrues from more critical space and computer time constraints.

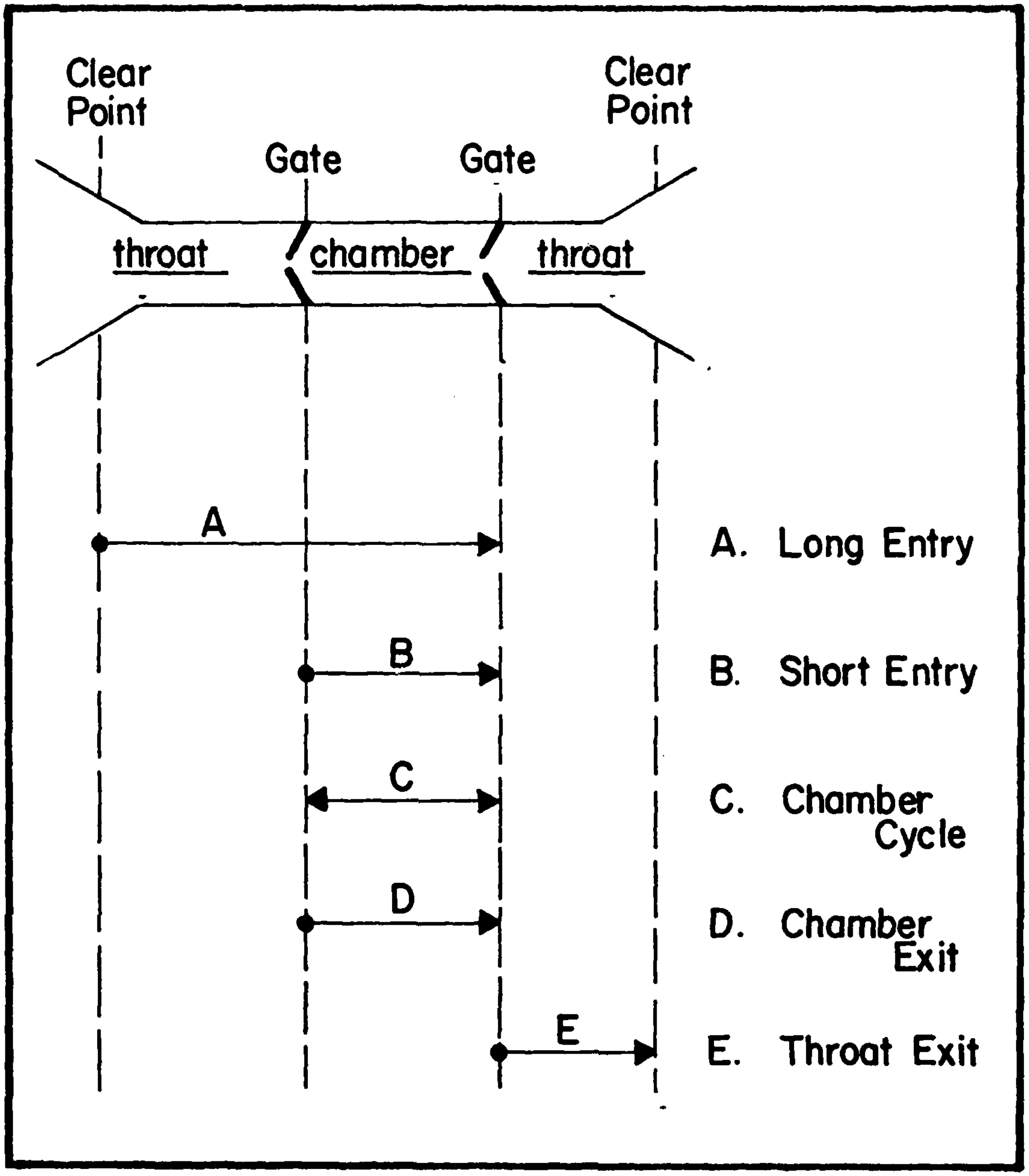


Figure 2-2. Locking Time Segments

C. DESCRIPTION OF THE NAVIGATION NETWORK

This class of data provides NETSIM II with a complete map of the waterway being simulated and operationally consists of three matrices. These matrices are called the table of next nodes, the facilities id table and the parallel facilities table.

1. Table of Next Nodes

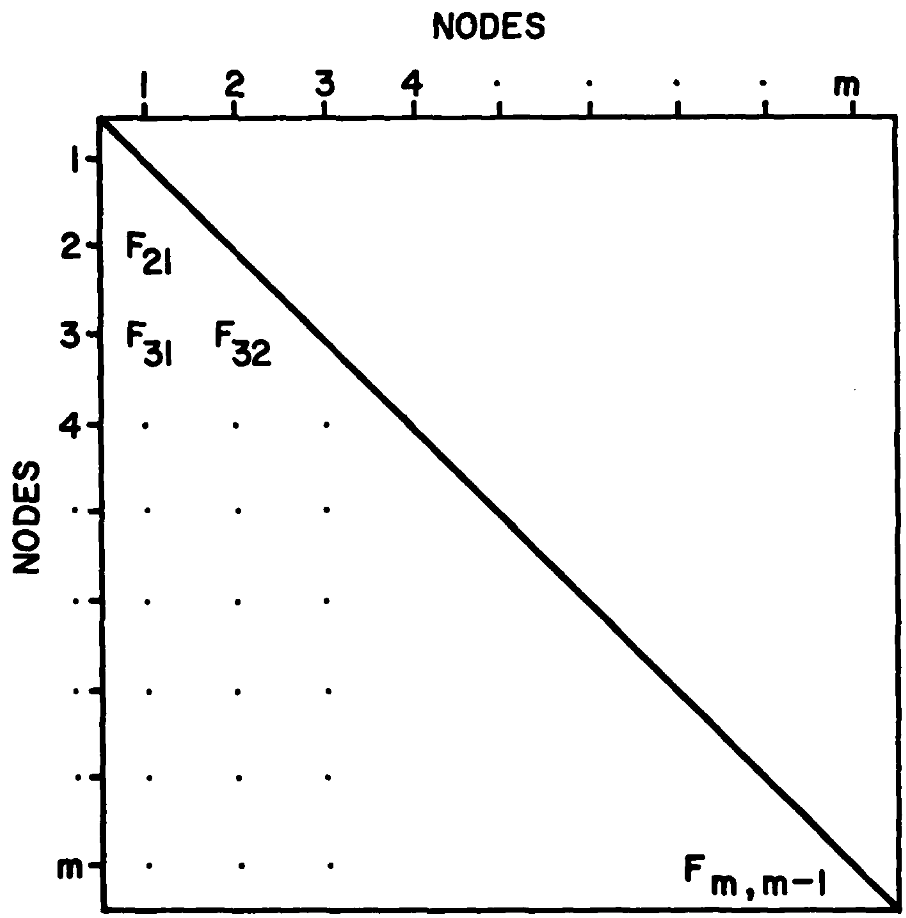
The table of next nodes gives the intermediate node between each node-port pair in the system. Structurally, this is a m x n matrix where m is the number of nodes and n is the number of ports. Thus, each cell in the matrix contains the next node encountered in traveling from the i^{th} node to the j^{th} port. In the event that parallel routes are present, the entry in the table of next nodes is a pointer to the parallel facilities table which lists the alternatives available.

2. Facilities Id Table

The facilities id table gives the intermediate facility between each pair of nodes in the system. This matrix is illustrated in Figure 2-3 for a system with m nodes. Since this matrix is symmetrical with the cells in the main diagonal being empty, the user is required to supply only the lower triangle of the matrix, as shown in the figure.

3. Parallel Facilities Table

Simulation of a system with parallel route options in NETSIM II requires first, a complete listing of each route option in terms of facilities and nodes and second, a mechanism to select one route over the other at any



$$F_{ij} = \begin{cases} \text{Facility between } i \text{ and } j \text{ where } i \text{ and } j \text{ are consecutive nodes} \\ \phi \text{ where } i \text{ and } j \text{ are not consecutive nodes} \end{cases}$$

Figure 2-3. Facilities ID Table

given time during the simulation. These requirements are met by the provision of the parallel facilities table. Since routes may not necessarily be of the same length, this matrix is a two-dimensional jagged array which provides the route description and the ETT function for each route option. Figure 2-4 illustrates this table.

D. COMMODITY ARRIVAL LIST AT PORTS

The commodity arrival list at ports constitutes an external event list in NETSIM II and thus reqnires a special format using the external event data notices (cards). Each notice supplies NETSIM II with various cargo shipments introduced at various ports. All shipments within a notice arrive at their ports at the same simulation time, however. Each shipment is described in terms of the following:

(1) port number into which the commodity is to be introduced

(2) commodity type

(3) destination

(4) quantity.

Normally, the user will wish to store this list on a separate card or tape file.

E. VESSEL FLEET DATA

Vessels are introduced into the system as exogenous events in NETSIM II, thus, the vessel data must also be supplied through the external event data notices. Each notice provides data for attributes of a single vessel and must describe the following:

(1) simulation time at which vessel enters system

(2) number of the port at which the vessel is to be introduced

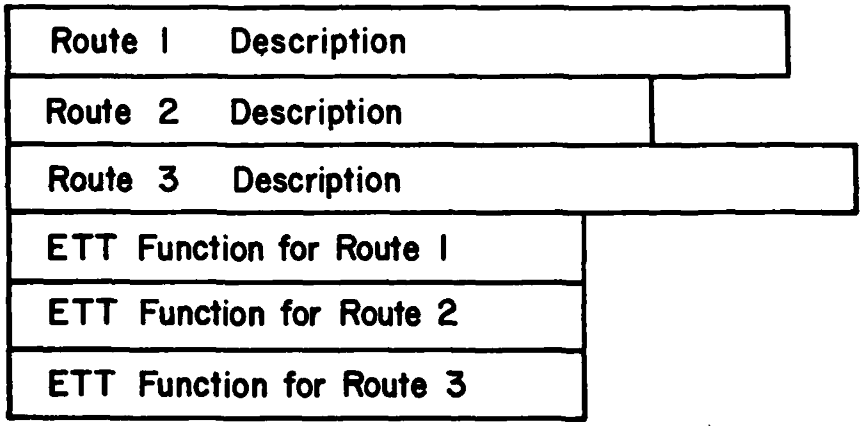


Figure 2-4. Parallel Facilities Table

(3) length

(4) horsepower

(5) capacity

(6) unloading rate (for self-unloaders only)

(7) draft

(8) classification

(9) code to indicate backhaul journey

(10) commodity tonnage

(11) commodity type

(12) origin

(13) identification number

Normally, the user will wish to store these data on a separate card or tape file.

F. ITINERARIES FOR SALTWATER VESSELS

Scheduling of saltwater vessels is handled quite differently from that of local bulk vessels in NETSIM II. The saltwater vessels enter the system from the Atlantic Ocean with predetermined itineraries. That is, the exact sequence of ports-of-call has been arranged before the vessel enters the system. To reflect this situation NETSIM II reads in a new itinerary to assign to each saltwater vessel as it is introduced into the system.

An itinerary consists of the following:

1. the number of ports-of-call,
2. for each port-of-call
   (a) the port number,
   (b) the fraction of the vessel's cargo capacity to be loaded at this port,

(c) the fraction of the vessel's cargo capacity to be unloaded at this port.

In NETSIM II, everything external to the navigation system (beyond the entrance to the St. Lawrence River) is given a single port number. We may refer to this as the "Atlantic Port." On any saltwater vessel itinerary, the Atlantic Port must be the last port-of-call.

CHAPTER 3. LOGIC AND OPERATIONS

This chapter describes the actual operations followed by NETSIM II in simulation processing. The main objective here is to provide the reader with an overall perspective of the logic and assumptions underlying the program. A highly detailed description of the programming considerations is not presented here; complete program documentation has been furnished separately to the Contracting Officer.[1]

A. PROGRAM OVERVIEW

Before presenting NETSIM II's entity, event and routine structures, a brief explanation of the overall global strategy is in order. This strategy is closely tied into SIMSCRIPT's programming capabilities. A reader familiar with SIMSCRIPT may therefore wish to skim over this section and concentrate on particular features of NETSIM II.

The basic unit of action in NETSIM II is a change in the status of an entity such as a vessel, lock, port, etc. These status changes may involve physical movement of a vessel from one point of the network to another or they may represent the accumulation of idle time as delay. The exact sequence in which changes occur and their effects on the system are characterized by <u>events</u> which are modeled in NETSIM II as subprograms and which are executed in zero simulated time, i.e., events representing status changes occur instantaneously.

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[1]All requests for listings, program decks, flow charts, etc., should be directed to the Contracting Officer.

Two classes of events are possible in NETSIM II. Exogenous events are events fed to the model externally. Commodity arrivals at ports during the simulation and vessel introductions into the system are exogenous events. These events are fed to the program from an external data source (magnetic tape or disk, punched cards, etc.). Endogenous events are events generated within the program. There are numerous endogenous events in NETSIM II and during the course of the simulation many schedule each other. For example, the event for a vessel to exit queue at a lock may upon its consummation schedule an event to enter the lock chamber. An event for a vessel to exit a lake may schedule an event for this vessel to enter the next reach.

Keeping track of the simulated time is accomplished automatically by SIMSCRIPT's timing routine. This is a special routine which accepts requests for the execution of events at specified future times and organizes them so that the event routines (subprograms) are called in the order of their scheduled event times. The simulation clock is advanced by the timing routine from one event time to the next in chronological order.[2]

Entities in SIMSCRIPT may either be permanent or temporary, the main distinction of relevance here being that temporary entities can be created and destroyed individually at various times during the simulation. Ports, reaches, lakes and locks are permanent entities in NETSIM II while vessels are the main temporary entities. Both types of entities have attributes and sets and can have owner-member relationships with each other. In these terms, simulation in NETSIM II can be simply described as the filing in sets,

[2]The simulation clock is advanced in discrete time increments which are not necessarily uniform; hence SIMSCRIPT is referred to as a discrete simulation language.

processing and removing from sets of the temporary entities (vessels) which are owned by the permanent entities. These operations must be carried out in an orderly manner as determined by transport supply and demand.

B. SIMULATION PROCESSING

The network of interest is represented in NETSIM II as a system of links and nodes. Reaches, lakes and locks constitute the links, while ports and link interfaces are the nodes. A simulation, then, involves representing the movements of vessels among and through these fixed facilities of the network.

1. Initialization

NETSIM II begins simulation by referencing the initialization routine which reads all the input data and the first event records on the exogenous events input sources. Little processing of the input values occurs since the model uses the data in raw form. The data are used to set up NETSIM II's entity set structures and system map matrices.

The initialization routine makes some data validity checks but these are minimal in nature. Since most of the input data are read in free form (i.e., without fixed format), omission of a particular item will normally result in some SIMSCRIPT error message for type, form or volume of the data, resulting in program termination. Therefore, it would behoove the user to be prudent in his data handling efforts and to fully eliminate all input errors.

When all the data are read in, the initialization routine is released from computer memory since it is no longer required for the simulation. Control is then passed to the timing routine which acts upon the earliest

scheduled exogenous event and references the appropriate event routine.

2. Movement Control

The actual simulation begins with the processing of the two exogenous events, commodity arrivals and vessel introductions. Both of these events occur within the realm of the port function, as will be explained later, with the eventual result that a vessel equipped with a cargo and a destination embarks on its journey. Its movement through the network is governed by the movement control routine.

Vessels may be of two general classifications. U. S. and Canadian bulk carriers are strictly local to the system. They carry no general cargo and they never leave the Seaway for overseas ports. During simulation their movements are determined dynamically by the destinations of cargoes available at ports. Saltwater vessels, on the other hand, enter the Seaway (from the Atlantic Ocean) with predetermined itineraries. Each itinerary lists the allowed ports-of-call for the vessel. These vessels carry general cargo as well as overseas bulk commodity shipments and are created and destroyed as they enter and leave the system (via the St. Lawrence River), respectively.[3] Associated with each vessel is a list of attributes which carry the following information:

1. Vessel type - whether saltwater, dry bulk or liquid bulk
2. Physical data
   (a) capacity
   (b) draft
   (c) horsepower
   (d) length
   (e) unloading rate (for self-unloaders)

[3]This is why vessels are characterized as temporary entities.

3. Dynamic system variables such as current location, destination and current cargo.

Recall that the destination and current cargo attributes are determined within the port function. Other dynamic system variables such as current location and next node are determined and continually updated by the movement control routine.

Within the movement control routine, the selection of each successive node in the path from the origin to destination is made by reference to the table of next nodes. The identification of the next facility to be encountered by a vessel is accomplished through the use of the facilities id table. However, if the vessel is faced with a parallel routes option, the entry in the table of next nodes is a pointer to the parallel facilities table which lists the alternatives available. A separate routine is then called to select the alternative (route) with the lower expected transit time.

A series of individual routines, referenced appropriately by the movement control routine, governs the timing of the vessel's movement through lakes, reaches and locks. The diagram in Figure 3-1 illustrates these interactions. The lake and reach routines are rather simple. Transit times for these facilities are based upon an average speed; in the case of the lake, the average speed is adjusted for vessel horsepower. In addition, a no-passing rule may be imposed upon any reach.[4] Vessel processing in the lock and port routines, by comparison, is quite complex and merits separate discussions.

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[4]The no-passing rule is the only delay constraint currently implemented in the reach routines. Other delays due to bridges, one lane passage, etc., are not explicitly considered. Due to the modular approach, however, it would not be difficult to incorporate these contingencies.

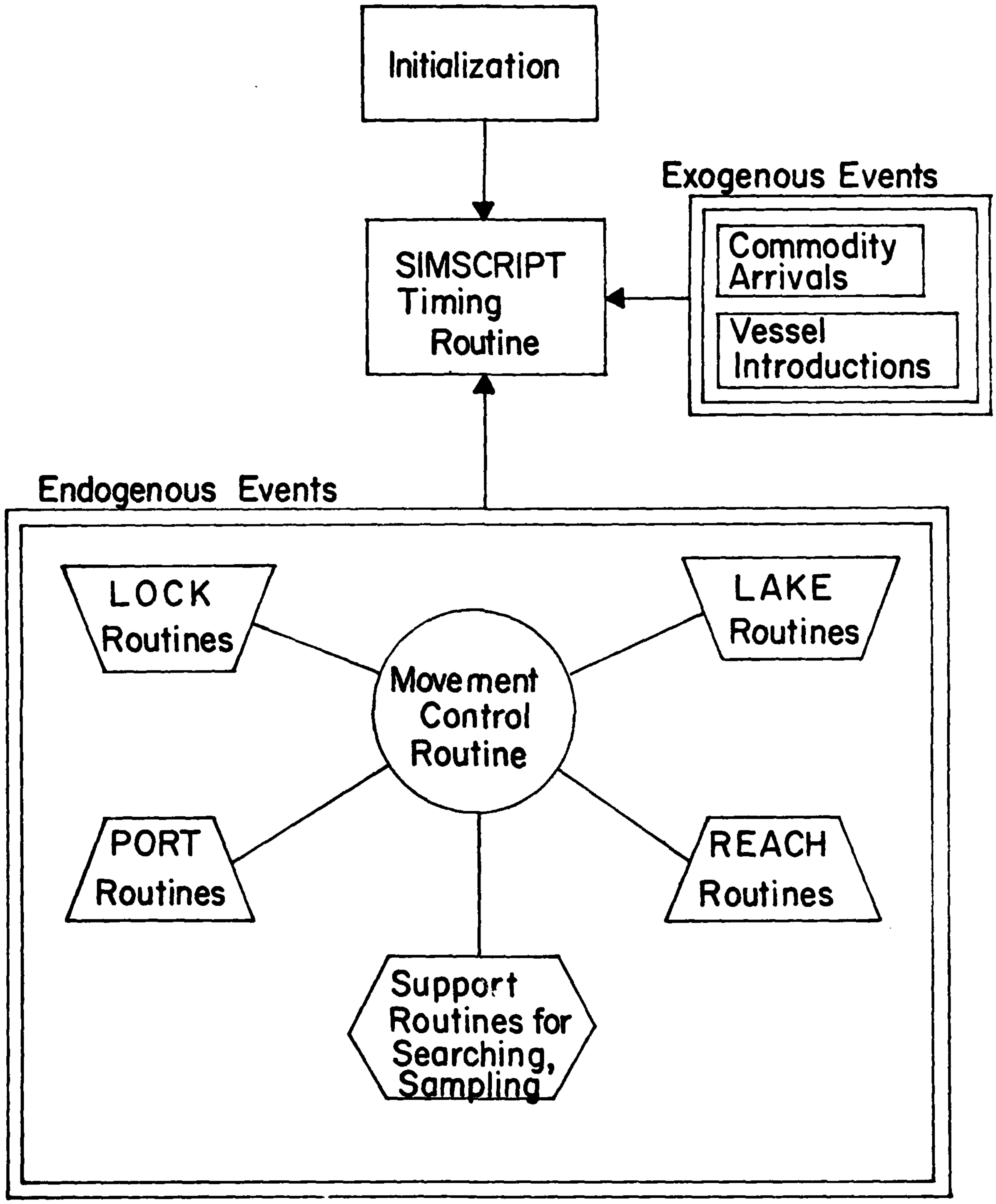

Figure 3-1. NETSIM II Program Flow

3. Lock Function

The lock function employs one main arrive-at-lock routine, and six event routines. The arrive-at-lock routine is initiated by the movement control routine when a vessel arrives at a lock. The subsequent operations provided within the lock function are schematically represented in Figure 3-2.

The arrive-at-lock routine can perform one of three changes in a vessel's status: it can allow the vessel to (1) enter queue; (2) enter short entry position just outside and clear of the entry gate; (3) enter lock chamber directly. A myriad of lock conditions govern the final selection of a particular status change and these are shown in Table 3-1. A unique feature of this selection process is the service look ahead capability which allows the program (or in the real world context, the lock master) to scan adjacent reaches for imminent lock arrivals. For example, when the lock is idle the program can commit the lock, recycling if necessary, to an imminent arrival in an adjacent reach in order to minimize its delay. When imminent arrivals are present in both reaches on either side of the lock, the program determines which vessel can arrive at the lock chamber earlier, taking into consideration the time required for recycling, etc.

Once a vessel is accorded its appropriate status change, its progress through the lock is performed through the event routines as events occur. This is perhaps best explained by way of an example. The following is an illustration of some normal processing that might be carried out by the lock function.

Clock = 1249

Vessel #	Event Time	Event Type
1	1262	End Cycle
2	1251	Leave Reach

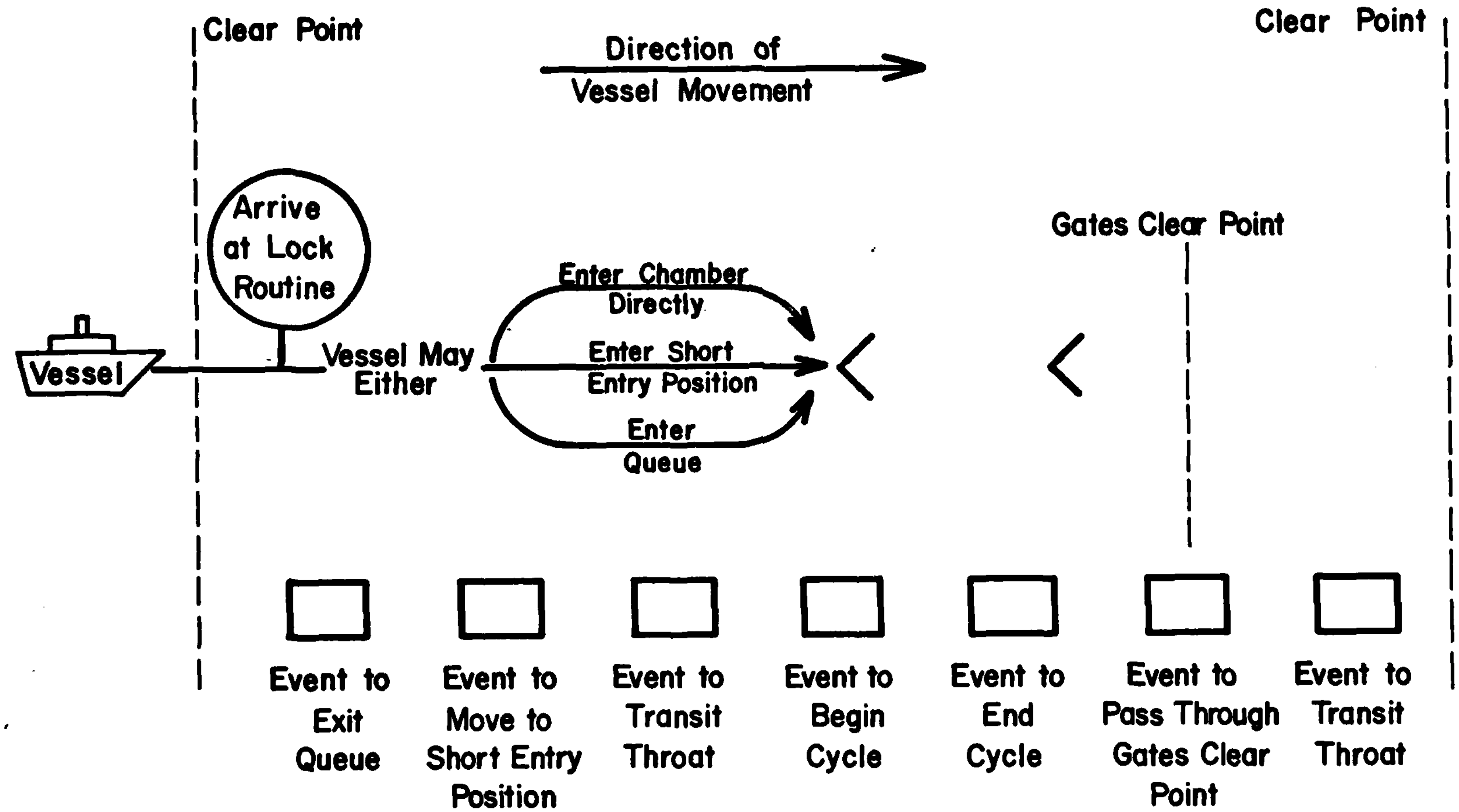

Figure 3-2. Schematic Representation of the Lock Function

TABLE 3-1. Lock Conditions in Arrive-at-Lock Routine

Vessel Status	Alternative Conditions
Enters queue	(1) upstream or downstream queue (or both) is occupied
	(2) the lock chamber or the lock throats contain a vessel moving toward vessel
	(3)* far reach contains a vessel moving toward arrival vessel and reach vessel can enter lock chamber earlier than the arrival vessel
enter short entry position	(1) lock is unoccupied but water level is not correct
	(2) lock contains a vessel moving in same direction, lock is otherwise empty but water level is not correct
	(3)* of all imminent arrivals, the subject vessel can make earliest chamber entry, but water level is not correct
enter chamber directly	(1) same as above three cases but water level is correct or will be correct at chamber entry time.

*Asterisk indicates use of the service look ahead capability whose explanation is given in text.

This example assumes that the current clock time is 1249. For the sake of simplicity, the lock is assumed to have only two vessels in its vicinity. Vessel #1 is in the lock chamber and awaits the end of the locking cycle at time 1262. Vessel #2 is scheduled to leave an adjacent reach at time 1251, and is assumed to be traveling in the same direction as the other vessel.

If there are no other events to precede it, the simulation clock is advanced to the time of the next earliest event, leave reach at time 1251. Vessel #2 is now at the lock clear point and the arrive-at-lock routine is invoked by the movement control routine. Consistent with the conditions in Table 1, the vessel performs entry into the short entry position, its arrival to be completed at time 1259. At that time the lock situation is as follows:[5]

Clock = 1259

Vessel #	Event Time	Event Type
1	1262	End Cycle

Note that Vessel #2 no longer appears in the above illustration as each event notice is destroyed upon its execution. The clock is now incremented to time 1262. The end cycle event routine is invoked to execute this event and it schedules an event to pass through gates clear point say at time 1267.

At time 1267, the pass through gates clear point event routine is called to execute this event. This routine performs two activities. First, it schedules Vessel #1 to exit the lock at time 1280 through the transit

[5] Actually, SIMSCRIPT provides an event notice to carry information pertinent to a particular event that is to occur. The illustrations given here are for the sake of convenience only.

throat event. Second, it scans the lock vicinity (queues, throats, adjacent reaches) and perceives Vessel #2 at short entry position. It then schedules a begin cycle event to take place at current clock time so that the lock can commence to recycle. The begin cycle event routine schedules an end cycle at time 1272. The lock situation is now as follows.

Clock - 1267

Vessel #	Event Time	Event Type
1	1280	Transit Throat
2	1272	End Cycle

The clock is now advanced to time 1272 and the end cycle event routine is called by the timing routine. The function of the end cycle event routine is different in this instance from previously because the lock chamber is empty. The routine therefore finds the vessel in short entry position and schedules it to enter the lock at time 1279 through the transit throat event. The new lock situation is shown below.

Clock - 1272

Vessel #	Event Time	Event Type
1	1280	Transit Throat
2	1279	Transit Throat

At time 1279 Vessel #2 enters the lock and the lock is cycled. The subsequent lock exit procedures for the vessel are performed in a manner similar to that for Vessel #1. The latter, of course, makes its lock departure at time 1280 and supervision over its passage is transferred back to the movement control routine.

In summary, the event routines in the lock function have three major functions: (1) execute the event for the subject vessel; (2) examine the lock situation for other vessels and trigger appropriate events; and (3) print relevant statistics for the event log. The last function is, of course, a mainstay of all event routines in NETSIM II.

It is useful to point out that the locking operation is always carried out incrementally in a number of stages. These stages are the lock clear point to the short entry position (unless vessel enters chamber directly), the chamber, the gates clear point and finally the lock clear point on the other side. A snapshot view at any single point of time would reveal a locking vessel in one of these stages, a concept found useful for the ETT channel choice mechanism as will be shown in a later section.

The queue discipline employed in NETSIM II is the SOQA (Serve Opposing Queues Alternately) Rule. This is complemented by the service look ahead capability mentioned earlier, which comes into play when the queues are empty. Changing the queue discipline in NETSIM II would be moderately difficult as changes would be necessitated in every routine within the lock function (but not anywhere else).

4. Port Function

Besides the lock function, the port function is the next most complicated process in NETSIM II. The complexity arises out of the fact that the port function plays a major role within NETSIM II's attempts to simulate the GL-SLS navigation system's vessel scheduling and cargo handling transactions. Although vessel processing at ports, per se, is rather simply handled, considerable efforts have been expended to inject some element of realism to the task of balancing transport supply and demand. The reader

therefore is urged to note carefully all assumptions and levels of aggregation so he may make his own judgement as to the model's validity. It is also necessary to point out that certain phases of the vessel scheduling and cargo handling procedures have been made external input into NETSIM II. For example, the logic for generation of commodity arrivals and itineraries for saltwater vessels resides in NETSIM II's support programs which are presented in Part 3 of this report.

The port function has three primary objectives:

1. The port routines control the amount of time a vessel spends in port and provide the logic whereby ports serve as the origins and destinations for vessels.
2. The port routines also provide the logic for the selection of cargo to be loaded onto a vessel (if any). An ancillary product of this task, in the case of local bulk carriers, is the creation of a dynamic scheduling mechanism since the destinations of these vessels are determined by the destinations of their cargoes.
3. The port function also contains the subprograms for processing NETSIM II's two exogenous events, commodity arrivals and vessel introductions. Thus each port contains an updated inventory list of commodities, vessels and port equipment classified by type and status (idle, busy, loading, etc.) during the simulation.

Each of these functions is discussed below.

a. Port Turnaround Time

A port is represented as having a number of berths classified into four types: general cargo, bulk liquid, grain and other dry bulk. Time

in port is the sum of four elements: (1) a small minimum time to enter and exit the port; (2) actual loading and unloading time, which is determined by the tonnage being transferred and the transfer rate for the cargo-handling equipment at a berth (or for the vessel if it is a self-unloader); (3) time spent in queues waiting for a berth or for cargo[6] and (4) a random factor to account for other delays.[7] This fourth element is calculated by drawing a random sample from an exponential distribution with a user specified mean (and variance).

b. Selection of Cargo

The heart of the cargo selection mechanism is a two-dimensional commodity inventory matrix maintained at each port. This matrix is a collection of updated commodity tonnages by type and destination. A vessel's cargo is taken from the matrix cell with the largest available tonnage, considering, of course, only those cargoes which the vessel is capable of carrying. Also, a vessel of length greater than 730 feet cannot accept a cargo which would require it to pass through the Welland Canal. A certain minimum amount of cargo must be available to qualify for loading onto a vessel. If no minimum load is available at the port, inquiry can be made at one or more nearby ports to determine whether a suitable cargo is available there. If so, that cargo is earmarked for the particular vessel and the vessel is dispatched to the nearby port for loading.

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[6]This delay time is not explicitly calculated as are the other elements, since delay is stochastically determined during simulation.

[7]For example, time to change berths, weather delays, etc.

One aspect of the bulk cargo selection and loading algorithm which may seem somewhat strange to the user at first is the fact that a vessel may "load" more cargo than is actually available, leaving the inventory level at the port temporarily negative. In the real world system, commodities do not flow uniformly into port as is likely to be the case in a simulation. Rather, they flow irregularly, and often the arrival of the commodity and the arrival of the vessel are coordinated so that the cargo is ready for loading when the vessel arrives. Since this coordination mechanism is not provided in NETSIM II, it would probably be too inflexible to restrict the vessel to the quantity of cargo that happens to be available. Rather, if cargo is available in a user specified minimum amount, the vessel is allowed to load to its capacity. Suppose, in a particular case, a minimum qualifying load of 10,000 tons of coal is available, but the vessel can carry 15,000 tons. Allowing the vessel to load 15,000 tons amounts to recognizing the fact that in real life the amount of coal shipped overland into the port would likely have been adjusted to equal the vessel's capacity.

Bulk carriers in the Great Lakes-St. Lawrence Waterway System do, in fact, make a large percentage of empty backhauls. In order to reflect this situation, the model allows for specification of the percentage of empty return trips by port-of-origin and commodity. During a simulation run, then, each loaded transit may or may not be followed by an empty return trip according to the appropriate given probability.

In addition to the mechanism just mentioned, there are two situations that can arise during the course of a simulation which lead to empty backhaul trips. First, in a case wherein a cargo queue (vessels awaiting assignment of cargo) is larger than the user specified limit for a port, vessels of that type arriving in port are sent back to their origins empty

after being unloaded. This is to prevent further buildup of the already excessive supply of vessels of a particular type. Second, is the case in which the amount of cargo awaiting transit at a port has built up beyond the allowable user-specified limit (in terms of number of days' influx). Then any vessel which is capable of carrying that type of cargo is marked for empty backhaul when it is dispatched from port. This signals its destination port to return it empty. Hence, in this situation of under-supply of vessels, the port assures, at least, that none of the (local bulk) vessels currently in its service will be lost to other routes.

c. Exogenous Event Processing

The port function contains the subprograms for processing NETSIM II's two exogenous events, commodity arrivals and vessel introductions.

Vessel introductions are handled through the create vessel event routine which reads data for the following vessel attributes:

length

horsepower

capacity

unloading rate (for self-unloaders)

draft

classification

code for empty backhaul

cargo tonnage

cargo type

origin.

In addition, the routine constructs values for the vessel's dynamic system variables such as current node, next node and destination. Finally, the routine introduces each vessel into the system at its origin port.

Commodity arrivals are handled through the commodity arrival event routine which reads the following data for each arrival shipment:

origin port

destination port

commodity type

commodity tonnage.

This event routine next updates the commodity inventory matrix and certain other variables used during the internal processing within port routines. It also initiates a check of vessels waiting in queues for cargo to see if suitable cargo is now available for these vessels.

d. Internal Vessel Processing Within Ports

The port function consists of five routines, one endogenous event routine and the two exogenous event routines mentioned above. Their names, functions and relationships are tabulated in Table 3-2.

When a vessel arrives at a port, the enter port routine checks the vessel's status with respect to its cargo. The vessel is entered into a berth (provided one is available, otherwise, it joins a berth queue) under three circumstances:

(1) Vessel is loaded and enters berth for unloading.

(2) Vessel is empty, however, a cargo is marked for this vessel at this port. This situation is the end product of an inquiry of nearby ports at its previous port stop.

(3) Vessel is empty, but a suitable cargo is found by the search for cargo routine.

TABLE 3-2. Port Function Routines

Type	Name of Routine	Function	Calling Routine (Scheduling Routine in case of event).
Routine	ENT.PORT	Determines vessel's status (loading, unloading, final destination, etc.), checks port equipment usage (availability of berths, etc.) and references appropriate routines.	MOVEMENT CONTROL EXT.BERTH CHK.CARGO.QUEUES
Event	EXT.BERTH	Executes vessel exit from berth, updates port equipment usage, vessel attributes and port attributes.	ENT.BERTH
Routine	ENT.BERTH	Executes vessel entry into berth, updates port equipment usage, vessel attributes and port attributes and schedules an exit from berth by calculating cargo transaction time.	ENT.PORT EXT.BERTH
Routine	CHK.CARGO.QUEUES	Checks to see if suitable cargo has arrived at port for vessels waiting in cargo queues.	COM.ARRIVAL
Routine	UPDATE.RATIOS	Updates port routines' internal variables.	ENT.PORT
Routine	SRCH.FOR.CARGO	Checks cargo inventories at ports to select suitable shipment for a vessel awaiting cargo.	ENT.PORT CHK.CARGO.QUEUES
Event	COM.ARRIVAL	Processes commodity arrivals, initiates check of cargo queues.	Timing Routine
Event	CREAT.VESSEL	Executes vessel introductions.	Timing Routine

The above three cases result in a call to the enter berth routine. As shown in Table 3-2, this routine executes vessel entry into berth, updates port equipment usage, vessel attributes and port attributes, and schedules an exit from the berth at an appropriate cargo transaction time calculated in the manner discussed previously under subsection (a) titled "Port Turnaround Time."

After a vessel unloads its cargo, a search is again made to find suitable cargo for a new journey unless this vessel is marked for an empty backhaul in which case it is sent back to its origin port. For a vessel that has loaded its cargo, the program determines whether this vessel should be marked for an empty backhaul. The criteria for determining when an empty backhaul should be made were described above. Three kinds of user-supplied constants which are involved in this mechanism can serve as calibration factors for the model. Those factors are (1) maximum cargo queue sizes, (2) maximum cargo inventory accumulation levels and (3) the probability that an empty backhaul will occur (in the case where a vessel has not already been marked for empty backhaul based on cargo queue size or cargo inventory level).

Besides the three just mentioned, there are many additional factors which permit the user considerable flexibility in calibrating the model and some of these are mentioned below. It is critical to point out the importance of this aspect of the simulation, since the establishment of a realistic simulation--a normative behavior--which may be used as a basis for comparison of other simulation runs is seldom achieved easily for large systems. More often than not, this difficulty is predicated on the desired levels of accuracy for simulation data. For example, the data needs for NETSIM II, despite the levels of aggregation, are indeed complex and will

require conscientious data collection efforts. The calibration factors, then, provide the user with some flexibility in achieving a realistic simulation.

The calibration factors within the port function include:

maximum inventory accumulation levels

probabilities of empty backhaul

minimum cargo levels

vessel loading factor

minimum turnaround time

random factor for turnaround time

number of nearby ports

maximum cargo queue sizes.

Other variables which may be construed as calibration factors are the distribution used to generate commodity arrivals and the parameters used to formulate itineraries for saltwater vessels. These variables physically exist external to NETSIM II, however.[8]

Figure 3-3 (a) and (b) is a simplified representation of the vessel handling logic (for bulk vessels only) in ports. These flow charts are intended to give the reader an understanding of the logic flow involved; they do not reveal in which subroutines the various logic segments reside. Processing for saltwater vessels is analogous but different in several respects due to the presence of pre-assigned itineraries and to the nature of the cargo selection procedure.

In several places throughout this report, reference is made to the vessel attribute, code for dedicated cargo. This is an internal code which

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[8]The lock and lake routines also use the vessel classification paramters as adjusting factors to modify vessel processing times.

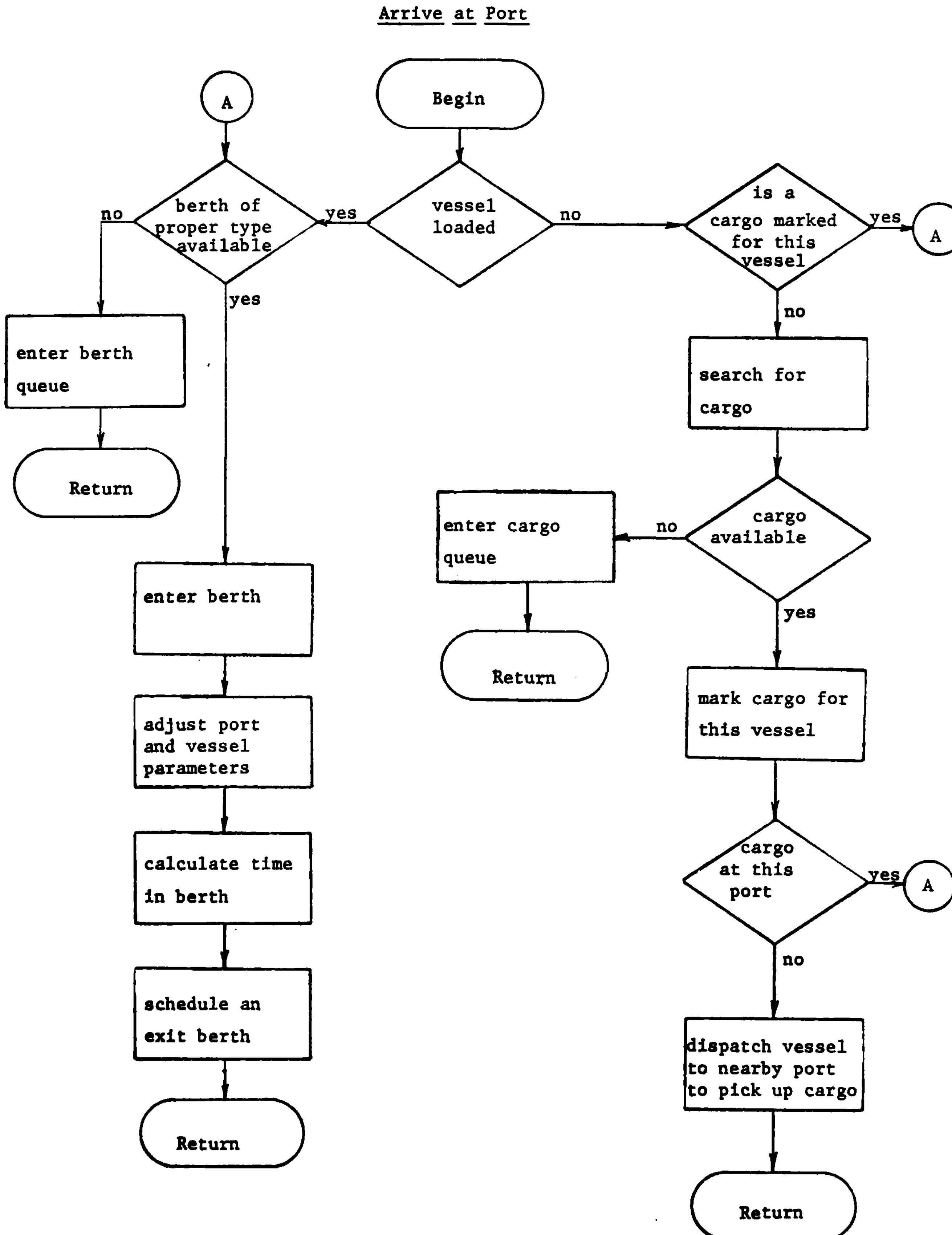

Figure 3-3(a). Port Logic Flow

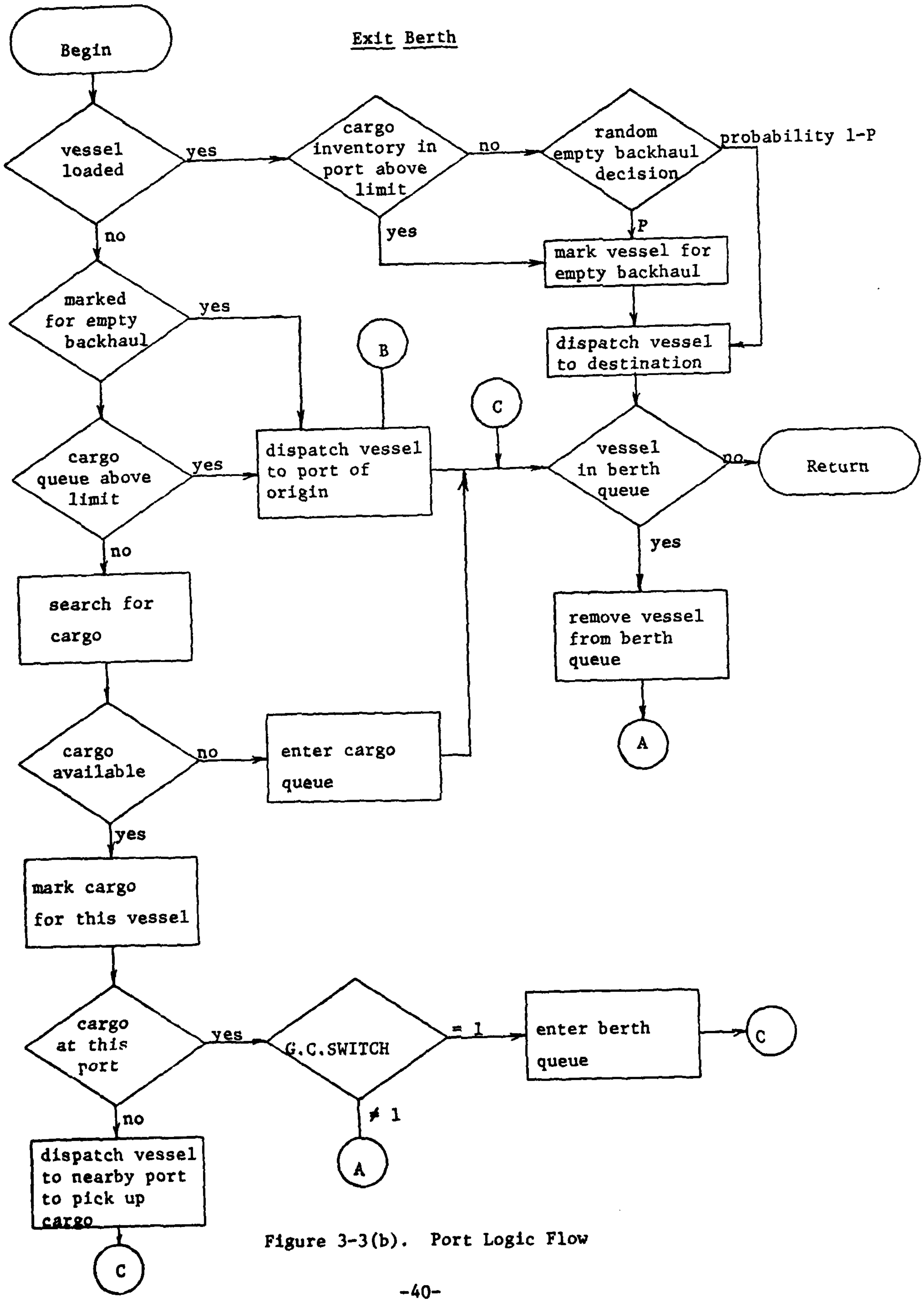

Figure 3-3(b). Port Logic Flow

is used in the port routines as follows. After a search for cargo has been carried out for a vessel, the cargo selected, if any, must be "earmarked" for the particular vessel. This is because the loading may not commence immediately; the vessel may either have to travel to a nearby port or wait in a berth queue first. The "earmarking" consists of the following steps:

(1) the vessel's cargo tonnage attribute is increased by the amount of cargo to be loaded;

(2) the commodity inventory matrix in the port is decreased by the amount of cargo to be loaded;

(3) the vessel's code for dedicated cargo (DED.CARGO) is set to the destination port number of the cargo to be loaded;

(4) the vessel's cargo type attribute is set to the type code for the cargo to be loaded.

Hence, the dedicated cargo code is an indicator to keep track of the destination of the cargo which has been earmarked for a vessel. The steps outlined above reveal a point which the NETSIM II user should keep in mind if it ever becomes necessary to examine an event log in detail. That is, that a vessel which appears to be loaded based upon the cargo tonnage attribute (non-zero) may indeed be empty and en route to pick up a selected unit of cargo. Both the cargo tonnage attribute and the dedicated cargo code must be examined to determine whether a vessel is loaded or empty.

5. Alternative Channel Choice Mechanism

Simulations of systems containing parallel route options require a procedure whereby vessels can be assigned to a particular route at various

times during the simulation. NETSIM II handles this contingency through the experience data bank (EDB) concept. A vessel confronted with a choice between two or more parallel routes to the same destination selects the route with the lower expected transit time. In order to establish the criteria for estimating such expected transit times, an EDB simulation run is made in which parallel route selections are made randomly and resulting transit times are recorded along with parameters which describe the state of the route segment of interest. Then, based on these simulation "experience" results, statistical analysis provides the relationships between the usage parameters for each parallel segment and the corresponding expected transit times. These relationships or ETT functions are then used in subsequent simulation runs for alternative route selection. In the context of the St. Lawrence Seaway system, the Welland Canal and the proposed Niagara Canal constitute such an alternative parallel route structure.

The alternative selector routine is employed in NETSIM II to perform the channel choice decision. When a vessel is confronted with parallel routes, this routine calculates current values for the usage parameters and utilizes the ETT functions to calculate the route with the lower expected transit time. Any route which physically precludes the passage of this vessel is automatically excluded from consideration (for example, lock dimensions may preclude certain large vessels). NETSIM II employs the following usage parameters listed by entity:

(1) Vessels

    length

    draft

(2) Reaches

    number of vessels in reach, i.e., reach traffic

    length of reach

(3) Locks

vessels in upstream queue

vessels in downstream queue

(4) Route

vessels in transit on route.

Additional parameters could be easily implemented in the alternative selector routine.

6. Monte Carlo Sampling

NETSIM II requires Monte Carlo sampling at various locations within the program. A separate routine has been provided within NETSIM II to centralize these tasks so that during simulation, whenever a random time is needed, the stochastic time calculations routine can be called to provide this element. This routine is used, for example, to provide the time elements from locking time frequency distributions, reach transit time distributions and lake transit time calculations.

The user can provide a maximum of ten distributions for each of the five locking segments (i.e., a total of fifty locking time distributions). Alternatively, the user can specify the use of a theoretical distribution from among eleven statistical functions supplied by SIMSCRIPT. These functions are listed in Table 3-3. In either case, the five locking segments may be further adjusted at user's specification to represent special conditions. The long entry, for example, can be adjusted to reflect both chamber entry from a stationary position at queue and a moving entry into chamber.

After sampling, the sampled time for a particular locking operation may be modified according to vessel attributes. In the real world the lock

TABLE 3-3. SIMSCRIPT Statistical Functions

Function	NETSIM II Code
BETA. F	1
BINOMIAL. F	2
ERLANG. F	3
EXPONENTIAL. F	4
GAMMA. F	5
LOGNORMAL. F	6
NORMAL. F	7
POISSON. F	8
RANDI. F	9
UNIFORM. F	10
WEIBULL. F	11

entry time for 300 ft vessel may be considerably less than that for a 730 ft vessel; the program allows the user to state explicitly the effect of vessel size on each of the locking operations.

Each reach requires two transit time distributions in NETSIM II, one for each direction of travel. They may again be either empirical or theoretical.

Transit through lakes is accomplished by reference to an intralake travel table which lists for each lake the average transit time between any two nodes on the lake. This average value is then adjusted by user supplied factors according to a vessel's horsepower. Current implementation in NETSIM II distinguishes vessels by the following horsepower categories:

	Horsepower	
Category	Lower Bound	Upper Bound
1	0	2500
2	2501	4000
3	4001	5000
4	5001	8000
5	8000	--

Category 3 vessels, i.e., vessels with horsepower between 4001 and 5000, serve as the average for the purposes of calculating lake transit times. Thus, the average times supplied in the intralake travel table are averages for category 3 vessels. The user must supply adjusting factors for categories 1, 2, 4 and 5 differentiated with respect to category 3. The average value is then adjusted either upward or downward corresponding to whether the horsepower is higher or lower than the average.[9]

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[9] The horsepower categories may be easily modified within NETSIM II. The current categories were formulated based on the availability of some crude data.

7. Representation of the Welland Canal

Representation of the Welland Canal as a collection of locks and reaches in NETSIM II presents a grave risk in that it ignores the effects of the rather sophisticated traffic control procedures [7, 8] governing vessel movements in the Canal. An interim solution to this problem consists of an alternative representation of the Canal as a single unique service facility.

This service facility is a simple waiting line model, mathematically categorized as M/G/1. The parameters of this model are an average service rate and the variance of the service distribution. These parameters were empirically determined through a statistical analysis of the <u>Vessel Transit Analysis</u> daily reports [9] for the months of June and August 1971.

As vessels arrive at the Welland Canal, the model seeks to predict their average delays through appropriate formulas in queuing theory. Total transit time through the Canal is then defined as the sum of this delay and the time for actual transit.

It should be fairly clear that the result of this approach is a gross approximation of the average vessel movement time through the Canal and not an exact or detailed representation of the Canal <u>per se</u>. Where feasible, alternative solutions such as dividing the system into subsystems or employing other analytical models should be diligently explored.

CHAPTER 4. OUTPUT

The primary NETSIM II output is an event log which is a description of all events that occurred during the simulation. Each event description lists the time of occurrence; vessel identification; vessel attributes such as length, current node, next node, cargo tonnage, commodity type and classification; facility identification and an event code which specifies the nature of the event. Normally, the user will wish to store this event log on an auxiliary unit such as a tape file so that it can be conveniently input to PROSIM, the statistical report generator.

NETSIM II provides a different form of output for an EDB run. The EDB output lists the transit times through each route, along with a snapshot view of the traffic conditions on the route when a vessel arrived at the channel choice point in the system. Thus, the actual transit time through a route may be statistically related to these usage parameters--system conditions--to generate ETT functions.

In addition to the event log, NETSIM II also prints out a running account of commodity inventory levels in ports during the simulation. This report is generated by the commodity arrival event routine, so that updated totals are printed just prior to arrival of commodities into port. In the report, commodities are grouped into 3 categories according to the cargo carrying capabilities of the three classifications of vessels: (1) general cargo, (2) liquid bulk and (3) dry bulk (including grain). Inventories of each type of commodity in each port are reported in two different sets of units, first, hundreds of tons and, second, number of days' influx. This second statistic is the inventory level that is used in determining whether

to mark a departing loaded vessel for empty backhaul (as described previously). A more detailed description of the inventory level report as well as of the event log is given in Appendix A.

CHAPTER 5. PROGRAM TESTS

Having labored through the program description so far, the reader may wonder, "How realistic is it? Does it yield valid results?" Since the program only approximates reality and since it contains many stochastic elements, a number of program tests are necessary to assure its validity and reliability. It is the purpose of this chapter to describe the nature of the tests that have been conducted on NETSIM II.

A. VALIDATION

The validity of a simulation is a measure of the extent to which it satisfies its design objectives. In the case of the NETSIM II-PROSIM model, the design objective was the development of a model with capabilities for comprehensive GL-SLS system simulations. Thus, assurance of validity requires the following:

(a) The theoretical structure of the model including all the assumptions must appear reasonable in relation to the real world phenomenon being simulated.

(b) The internal programming logic must be shown to be correct.

(c) The model must have the capability for specified applications.

Much of the theoretical consideration in NETSIM II, particularly that concerned with locking operations and to a lesser extent the lake, reach and vessel movement control operations, are derived from an extension of previous work. The port function is an exception to this, and during the course of its development a considerable amount of time was expended on discussions with Great Lakes shippers, carriers, shipping agents and

government agencies to ensure the incorporation of the major concepts and principles underlying GL-SLS navigation. Attempts were made to minimize the twin problems of including too much detail and/or excluding major operational concepts by limiting the scope of the model to its design objectives and by the use of calibration and adjusting factors. The latter will be considered more fully in the next section.

Program tests on the NETSIN II program fall into two categories:

(1) testing of each individual component in the program to insure that it is internally correct in terms of both modeling logic and the programming statements;

(2) hooking the individual components together and testing the entire program.

While the former facilitated debugging and ease of interpretation, it is the latter that is of the ultimate interest since assurance of each individual component when considered in isolation does not necessarily imply the adequacy of the entire program. Tests described below are of the second type.

The bulk of the testing of the NETSIM II program was carried out on a hypothetical navigation system network. The hypothetical network is very similar to the GL-SLS, but with a greatly reduced number of ports, locks, reaches, vessels and commodities (for one form of this network, see Appendix B).

The bulk of the analysis consisted of detailed examinations of the event log output generated by the program. Using the small network as opposed to a larger one offered a distinct advantage here since the tested network, simulated typically for ten or twenty-day periods, exhibited most of the situations arising in larger and longer simulations and yet was easier to interpret and analyze.

The event log analysis took the following four forms.

(1) Examination of the event log in its natural form, that is, in the chronological order of events. A partial listing of the event log is shown in Table 5-1 accompanied by an interpretation. The focus of this type of an examination was on the vessel handling and vessel movement aspects of the simulation program so as to assure proper interplay among the program routines.

(2) Examination of the event log sorted first by vessel and then by time. This allowed an analysis of the movements of each individual vessel in the system. It thus provided systematic information on the times spent at various points in the system including delay, processing and transit times and generated the data needed to calculate fleet inventories at ports, port-to-port routes and other locations in the system.

(3) Examination of the event log sorted first by facility and then by time. This simple arrangement facilitated analysis of each facility usage as can be readily seen in Table 5-2 which gives a partial listing for a lock. With this tool, each event occurrence could be examined and related to the modeling logic.

(4) Analysis of the output tables generated by PROSIM: These tables contain statistical summaries of the event log sorted by vessel, facility, event and time.

TABLE 5-1. Partial Listing of the NETSIM II Event Log

Vessel Identification Number	Vessel length in tens of feet	Vessel's current node	Vessel's next node	Vessel's cargo tonnage in hundreds of tons	Commodity type	Code for dedicated cargo	Vessel classification	Facility identification number	Event Code	Simulation Time	Event Log Interpretation
19	60	15	14	142	3	0	3	16	4102	1743.	Vessel #19 carrying 14,200 tons of dry bulk cargo exits reach #16.
19	60	14	13	142	3	0	3	13	1304	1743.	Vessel #19 begins direct entry into chamber at lock #13.
19	60	14	13	142	3	0	3	13	2301	1743.	Lock #13 completes recycle to ready chamber for vessel #19.
26	60	17	18	142	3	0	3	26	3102	1745.	Vessel #26 carrying 14,200 tons of dry bulk cargo exits lake #26.
26	60	18	19	142	3	0	3	18	4101	1745.	Vessel #26 moving from node #18 to node #19 enters reach #18
73	60	5	16	0	1	0	2	25	3102	1751.	Vessel #73, a liquid bulk vessel currently empty exits lake #25.
73	60	16	17	0	1	0	2	17	4101	1751.	Vessel #73 enters reach #17 representing St. Clair River.
19	60	14	13	142	3	0	3	13	2001	1756.	Vessel #19 arrives in chamber at lock #13.
55	60	22	10	142	4	0	3	20	4102	1772.	Vessel #55 carrying 14,200 tons of dry bulk cargo exits reach #20.
55	60	10	21	142	4	0	3	19	4101	1772.	Vessel #55 enters reach #19.
19	60	14	13	142	3	0	3	13	2101	1775.	Vessel #19 having cycled to the other side begins chamber exit.
89	50	10	10	85	1	0	1	10	9160	1775.	Vessel #89, a saltwater vessel, exits berth at port #10 after unloading some cargo.
89	50	10	10	142	1	12	1	10	9150	1775.	Vessel #89 now begins to load some cargo at same berth.
19	60	14	13	142	3	0	3	13	2403	1781.	Vessel #19 having finished chamber exit now begins throat exit.
19	60	14	13	142	3	0	3	13	1801	1789.	Vessel #19 exits lock #13 representing Sault Ste. Marie lock
19	60	13	1	142	3	0	3	23	3101	1789.	Vessel #19 enters lake #23 representing Lake Superior and heads toward port #1 representing Duluth/Superior.

TABLE 5-2. Partial Listing of the NETSIM II Event Log Sorted by Facility

Vessel Identification Number	Vessel length in tens of feet	Vessel's current node	Vessel's next node	Vessel's cargo tonnage in hundreds of tons	Commodity type	Code for dedicated cargo	Vessel classification	Facility identification number	Event Code	Simulation Time	Event Log Interpretation
23	60	14	13	142	3	0	3	13	2402	4447.	Vessel #23 begins throat exit. Queue in front is not empty.
23	60	14	13	142	3	0	3	13	1801	4456.	Vessel #23 traveling upstream exits lock #13.
20	60	13	14	0	3	0	3	13	1401	4456.	Vessel #20 going downstream exits queue to enter chamber.
20	60	13	14	0	3	0	3	13	2001	4472.	Vessel #20 enters chamber.
20	60	13	14	0	3	0	3	13	2101	4489.	Chamber completes cycling to the other side and vessel begin chamber exit.
20	60	13	14	0	3	0	3	13	2403	4494.	Vessel begins throat exit, lock is idle.
20	60	13	14	0	3	0	3	13	1801	4501.	Vessel #20 exits lock.
14	60	13	14	0	3	0	3	13	2301	4523.	Lock #13 recycles to other side to receive vessel #14.
14	60	13	14	0	3	0	3	13	1304	4523.	Vessel #14 begins direct entry into chamber.
14	60	13	14	0	3	0	3	13	2001	4554.	Vessel #14 traveling downstream enters chamber.
45	60	14	13	142	3	0	3	13	1103	4555.	Vessel #45 traveling upstream enters queue.
14	60	13	14	0	3	0	3	13	2101	4569.	Vessel #14 begins chamber exit.
14	60	13	14	0	3	0	3	13	2402	4575.	Vessel #14 begins throat exit. Queue in front is not empty.
15	60	13	14	0	3	0	3	13	1106	4576.	Vessel #15 traveling downstream enters queue and sees vessels #14 and 45.
14	60	13	14	0	3	0	3	13	1801	4585.	Vessel #14 exits lock.
45	60	14	13	142	3	0	3	13	1401	4585.	Vessel #45 exits queue to enter chamber (use of SOQA rule).

Program tests of the forms indicated above confirmed the general workability of the simulation program. Also, a run was made on a system very nearly representing the GL-SLS in order to demonstrate the feasibility of simulating a system of that magnitude (for a brief description of this simulation, see the accompanying Summary Report [10]).

B. CALIBRATION

The object of the calibration process is to determine the degree of error that exists within the model and establish a procedure for dealing with it. During the course of program testing, need for several calibration and adjustment factors became evident. This need arose in the following areas:

1. Port Turnaround Time

The deterministic components of port turnaround time are a minimum time to enter and exit a port, the actual loading and unloading time as determined by the tonnage being transferred and the transfer rate for the cargo-handling equipment at a berth (or for the vessel if it is a self-unloader), and the time spent in queues waiting for a berth or for cargo. In addition to these, a stochastic component was deemed necessary to account for other delays such as time to change berths and weather delays.

2. Oversupply of Vessels at Ports

Oversupply of vessels at ports may be manifested in a large number of vessels waiting in queues for cargo at the expense of an undersupply of vessels at other locations in the system. To correct this situation, an automatic limiting factor was implemented so that when the number of vessels in a port waiting for cargo exceeds this limit, other vessels will be sent back to their ports of origin empty rather than being allowed to remain and wait for cargo.

3. Undersupply of Vessels at Ports

Undersupply of vessels may result in an abnormally high cargo inventory at a port. To correct this situation, another limiting factor was incorporated so that when a commodity awaiting transit accumulates beyond this limit in a port, vessels departing loaded will be marked for empty backhaul. This is to ensure that they will be returned to this port--where they are sorely needed--rather than being assigned to some other movement.

This arrangement may not be completely satisfactory, however, since a port may have a "small enough" transaction of a particular commodity that the inventory may not reach the limiting factor for a considerable period of time, yet it may be in dire need of vessels. On the other side of the coin, this situation may result in "captive" vessels which may not have a suitable cargo of sufficient quantity to transport and may therefore wait in the cargo queue for a long period of time. To deal with these problems, a set of "nearby" ports can be specified for each port so that when a vessel cannot find a suitable cargo in its current port, it will search for cargo in "nearby" ports.

4. Empty Backhauls

Bulk carriers in the GL-SLS system do engage in a large percentage of empty backhauls. In order to reflect this situation, the percentage of empty return trips is specified for each port-of-origin and commodity.

5. Imbalance Between Commodities and Vessels

If there is a systematic imbalance between the amount of cargo to be transported and the transport equipment units available, then the number and sizes of vessels in the fleet and the average vessel loading factor may

be used to arrive at an equilibrium. This last factor determines the average vessel cargo tonnage as a fraction of the vessel's stated capacity.

In addition to the specific factors stated above, a number of adjustment factors based on differences in vessel attributes are used to adjust average vessel processing and transit times. For example, the transit time through a lake computed from the intralake travel table is an average time for a vessel of 4,001-5,000 horsepower. This time is adjusted upward or downward depending on the actual vessel horsepower (the exact specification of these adjusting factors is given in Appendix A, the NETSIM II Users' Manual).

In conclusion, a number of calibration factors have been implemented to reduce the error that exists within the model. Stable values for these factors have not been determined, however, since an accurate data base for such an endeavor (on the GL-SLS system) was not available at the time.

APPENDIX A

NETSIM II USER MANUAL

A. INTRODUCTION

This manual provides the information needed to prepare the input data for and interpret the output of the NETSIM II portion of the simulation package. It is assumed that the reader has a thorough understanding of Chapters 1 and 2 of this volume, and is familiar with the contents of Chapters 3 and 4. Attention here is focused on input/output formats rather than on system or programming logic. However, a working knowledge of the program logic flow will be useful in resolving many of the problems encountered in developing the input data files. For this, the reader is referred to Chapter 3.

In addition to familiarization with Part I of this volume, the user is urged to consult references [11] and [12] dealing with the SIMSCRIPT language.

B. NUMBERING CONVENTION IN NETSIM II

The numbering convention in NETSIM II consists of a few restrictions which have been adopted for two reasons. First of all, some restrictions are absolutely vital from the viewpoint of program efficiency. NETSIM II takes heavy advantage of SIMSCRIPT's packing capabilities--that is, the storing of multiple data values in a computer word. This also implies, however, that the packed values must be much smaller in magnitude than when they are not packed. An example of this restriction involves the vessel attribues, length, horsepower and tonnage. Due to packing, length must be expressed in tens of feet, horsepower in hundreds and tonnage in hundreds of tons.

The second reason for adopting the numbering convention is that it facilitates programming and error detection. Data validity checks can be built into the program to a greater extent and errors can be pinpointed more easily. The numbering convention also reduces the physical size of the program and makes it easier for the user to interpret through its basic structure.

The number conventions consist of the following:

1. Ports, locks, reaches and lakes must be numbered sequentially in order.

2. Ports and other non-port nodes must be numbered sequentially in order. For example, consider a system with 8 ports, 3 locks, 7 reaches, 5 lakes and 12 nodes. Ports must be numbered 1 through 8, locks 9 through 11, reaches 12 through 18, lakes 19 through 23 and non-port nodes 9 through 12 (there are 8 port-nodes and 4 non-port nodes). Note that locks and non-port nodes are numbered sequentially after ports. All ports above the Welland Canal should have numbers lower than those below Welland. The "Atlantic Port" should have the highest number. A good guide rule is to number ports sequentially from "upstream" to "downstream."

3. Vessel classifications must be numbered as follows:

   1 = saltwater vessel

   2 = liquid bulk vessels

   3 = dry bulk vessels.

4. Berth types at ports must be classified as follows:

   1 = general cargo berths

   2 = dry bulk (excluding grain) berths

   3 = grain berths

   4 = liquid bulk berths.

5. The only restrictions on the commodity numbering system are that general cargo must be the last commodity type and that all dry bulk commodities including grain must be numbered sequentially as a group. Thus, if there are 8 commodities, the following numbering system is acceptable.

Commodity Type	Description		Special Codes	Item
1	coal		DRY.LO	A19
2	sand			
3	grain	dry	GRN.INDEX	A18
4	stone	bulk		
5	iron			
6	cement		DRY.HI	A20
7	liquid bulk		LIQ.INDEX	A17
8	general cargo		GEN.INDEX	A16

Note: the last two columns indicate special codes, and their sequential item numbers as they appear in the next section under input formats.

6. A system containing parallel routes requires an identification number for each of these routes. This number must be a four digit code.

C. INPUT DATA FORMATS

A NETSIM II data deck consists of the five classes of data described in Chapter 2. Some of these data are in fixed format and others can be input in free-form. For the latter, there are two governing restrictions. First, each datum must be separated from its adjoining data by at least one blank. Second, a datum must not be continued from one card to the next.

Data may be punched as either real or integer. The important thing to remember about the free-form concept is that the program reads free-form input as a continuous stream of values. Successive numerical values are read and assigned to corresponding variables in the read command. The location of a particular datum on a card is not considered, as long as it is properly positioned relative to other data. Unless otherwise indicated, all data below can be input in free-form.

The card format descriptions below are preceded by an item number, consisting of a letter and a number. The letter refers to the corresponding section of Chapter 2 of this volume, and the numbers are sequential. These item numbers are relevant only to this manual, and must not appear on the data cards.

Some simulation input data are not required for an EDB run. Data cards that should be deleted from an EDB input deck consist of the items for ETT functions as indicated in the text below.

Card Format Specifications

Item Number	Contents
A1	SEASON.LENGTH This is the total simulation time including any warm-up time needed to achieve steady state.
A2	EDB.CODE This code is set to 1 for an EDB run, 0 otherwise.
A3	LOOK.AHEAD.CODE This code is set to 1 to use the service look ahead feature, 0 otherwise.

Item Number	Contents
A4	PARA.CODE This code is set to 1 if the system contains one or more parallel route options, 0 otherwise.
A5	TAPE.DRIVE This field provides the output unit number for the NETSIM II event log output. This number must agree with the data set reference number (DSRN) given in the Data Definition card (DD card for IBM OS/360 JCL).
A6	HI.PORT Identification number of the highest numbered port.
A7	N.PORT Number of ports.
A8	HI.LOCK Identification number of the highest numbered lock.
A9	N.LOCK Number of locks.
A10	HI.REACH Identification number of the highest reach.
A11	N.REACH Number of reaches.
A12	HI.LAKE Identification number of the highest lake.

Item Number	Contents
A13	N.LAKE Number of lakes.
A14	SWITCH.FOR.WELLAND This code is 1 if NETSIM II's representation of the Welland Canal is to be used, 0 otherwise.
A15	NO.OF.NODES Number of nodes in the system.
A16	GEN.INDEX This is the code representing general cargo.
A17	LIQ.INDEX This code represents liquid bulk cargo.
A18	GRN.INDEX This code represents grain cargo.
A19	DRY.LO This code represents the lowest numbered dry bulk cargo (including grain).
A20	DRY.HI This code represents the highest numbered dry bulk cargo (including grain).
A21	ATLANTIC.PORT Identification number of the port located at the eastern end of the simulation system. This port serves as the entry and exit point for saltwater traffic (should be the same as Item A6 in most cases).

Item Number	Contents
A22	STREAM Index number representing SIMSCRIPT-provided random number streams. This number must have a value between 1 and 10. This index is used for random sampling from probability distributions for saltwater vessels' cargo selection.
A23	STREAM1 Index number as above and used to sample from probability distributions for empty backhaul.
A24	STREAM2 Index number as above and used for the calculation of cargo transaction time in a berth.
A25	G.C.SWITCH The general cargo switch can take on a value of either 0 or 1. If its value is 0, a saltwater vessel is permitted to unload and load its cargo as a sequential operation in the same berth. Otherwise, if the value is 1, the vessel must relinquish its berth after an unloading process to another vessel awaiting this berth.

Item Number	Contents
A26	ERIE.EAST Identification number of the highest numbered port west of the Welland Canal.
A27	DR.MAX The maximum desired number of days' commodity accumulation for dry bulk cargo at ports. When this number is exceeded at any port, dry bulk vessels leaving port loaded will be marked for empty backhaul.
A28	LR.MAX As above for liquid bulk cargo.
A29	NUM.COMMOD Number of commodities. There is no limit on this number in NETSIM II.
A30	COMM.DEVICE Input unit with the commodity arrival event data.
A31	SHIP.DEVICE Input unit with the vessel introduction event data.
A32	1.CLASS Vessel length upperbound for Class 1, in tens of feet.
A33	2.CLASS Vessel length upperbound for Class 2, in tens of feet. Note that vessels of length less than 1.CLASS are said to be in Class 1;

Item Number	Contents
	vessels of length between 1.CLASS and 2.CLASS in Class 2 and vessels of length over 2.CLASS in Class 3.
A34	IT.DEVICE
	Input unit containing itineraries for saltwater vessels.
A35	RAT.UNIT
	Output unit for printing commodity inventories at ports.
A36	LK.2500HP.OR.LESS.ADJ
	Adjusting factor for vessels of 2500 horsepower or less, expressed in percentage. This factor is used to modify an average lake transit time obtained from the intra-lake travel table. For example, an entry of '108.5' would indicate that a vessel with 2500 horsepower or less requires 8.5 percent longer than the average figure in the table.
A37	LK.4000HP.OR.LESS.ADJ
	Adjusting factor for vessels of horsepower between 2501 and 4000 inclusive, expressed in percentage.
A38	LK.5000HP.OR.GRT.ADJ
	Adjusting factor for vessels of horsepower between 5001 and 8000 inclusive, expressed in percentage.

Item Number	Contents
A39	LK.8000HP.OR.GRT.ADJ Adjusting factor for vessels of horsepower greater than 8000 expressed in percentage.
B1	VSL.LDG.FACTOR Vessel loading factor expressed as a decimal fraction. A value of 1.0 indicates that a vessel would, if suitable cargo was available, load fully up to its capacity.
B2	MIN.CARG(1) , MIN.CARG(2) , MIN.CARG(3) A vector containing the minimum cargo levels (for loading) for general, dry bulk and liquid bulk cargoes, respectively (hundreds of tons). Cargoes in smaller amounts do not qualify for loading.
B3	BER.CONV(1) , BER.CONV(2) , . . . , BER.CONV(NUM.COMMOD) A vector containing the berth conversions for each commodity. For a system with n commodities, there are n elements in this vector. To illustrate its use, a value of 1 for BER.CONV(3) indicates that commodity type 3 must be processed (loaded or unloaded) in berth type 1. There are four berth types in NETSIM II (correspondingly, the elements of this vector may take on only four values: 1, 2, 3 or 4): 1 = general cargo berth; 2 = dry bulk berth; 3 = grain berth; 4 = liquid bulk berth.

Item Number	Contents
	Items B4 through B11 in entirety must be repeated for each port until all the ports are exhausted.
B4	The following are in 10-column fields, right justified (2 I 10, 3 D(10,0), 2 I 10)

```
cc   1-10  port identification number
    11-20  lower bound on port turnaround time, minutes
    21-30  dry bulk cargo influx rate, hundreds
           of tons per day
    31-40  liquid bulk cargo influx rate, hundreds
           of tons per day
    41-50  general cargo influx rate, hundreds
           of tons per day
    51-60  port depth, feet
    61-70  number of nearby ports
```

B5	POR.NUM(NRBY.PORT)
	A vector containing the identification numbers for each nearby port. The numbers are given in free form.
B6	The following are in 10-column fields, right justified. The first element is integer and the next four are real (I 10, 4 D(10,0)).

```
cc   1-10  port identification number
    11-20  general cargo unloading rate,
           hundreds of tons/minute
    21-30  dry bulk cargo unloading rate,
           hundreds of tons/minute
    31-40  grain unloading rate, hundreds of
           tons/minute
    41-50  liquid bulk cargo unloading rate,
           hundreds of tons/minute
```

B7	The following are in 10-column fields, right justified. The first element is integer and the next four are real (I 10, 4 D(10,0)).

Item Number	Contents

cc	1-10	port identification number
	11-20	general cargo loading rate, hundreds of tons/minute
	21-30	dry bulk cargo loading rate, hundreds of tons/minute
	31-40	grain loading rate, hundreds of tons/minute
	41-50	liquid bulk cargo loading rate, hundreds of tons/minute

B8

The following are in 10-column fields, right justified. The first element is integer and the next four are real (I 10, 4 D(10,0)).

cc	1-10	port identification number
	11-20	random factor for general cargo vessels' port turnaround time
	21-30	random factor for dry bulk cargo vessels' port turnaround time
	31-40	random factor for train vessel's port turnaround time
	41-50	random factor for liquid cargo vessel's port turnaround time

Note: the factors given above are interpreted as the mean of an exponential distribution in NETSIM II.

B9

The following are in 10-column fields, integer, right justified (3 I 10).

cc	1-10	port identification number
	11-20	dry bulk cargo queue limit
	21-30	liquid bulk cargo queue limit

Note: when the number of vessels awaiting cargo is greater than the limit, all other vessels of that type are sent back to their origins empty after unloading.

B10

The following are in 10-column fields, integer, right justified (5 I 10).

Item Number	Contents
	cc 1-10 port identification number 11-20 number of general cargo berths 21-30 number of dry bulk (excluding grain) berths 31-40 number of grain berths 41-50 number of liquid bulk berths
B11	For a system with n commodities, the format is (I 10, D n(5,2)), right justified. cc 1-10 port identification number 13-15 •xx probability of empty backhaul for commodity 1 18-20 •xx 23-25 •xx 28-30 •xx . . .
	Items B12 through B16 in entirety must be repeated for each lake until all the lakes are exhausted.
B12	ID.LAKE Identification number of lake.
B13	NUM.OF.LAKE.NODES The number of nodes (including ports) on lake.
B14	LAK.PARA.CODE This code is 1 if the lake is part of a parallel routes set, 0 otherwise.
B15	CDF.LTT This code is 1 if the lake transit time distribution is specified empirically, 0 if a theoretical distribution is to be used.

Item Number	Contents
B16	Lake transit time distribution

Note: Transit times for passage through lakes should normally be supplied through the INTRALAKE. TRAVEL.TABLE. In certain simulations where lakes are simplistically represented, however, it may be easier to specify the use of a theoretical function without great loss of accuracy. For example, representation of Lake St. Francis on the St. Lawrence Seaway as a lake (rather than a reach) may warrant a theoretical function to calculate travel time from one end of the lake to the other.

Theoretical distribution.

This specification requires five elements:
1st element = lake identification number
2nd element = NETSIM II code for SIMSCRIPT function (refer to Table A-1)
3-5 elements = parameters[1] of SIMSCRIPT function (refer to Table A-1).

INTRALAKE.TRAVEL.TABLE

The table is read row by row. The first row contains, in its first column, the identification number of the lake. Columns 2 through n + 1 of the first row contain the identification numbers of each of the n nodes on the lake. The first column of rows 2 through n + 1 contains the identification numbers of each of the n nodes. Columns 2 through n + 1 of rows 2 through n + 1 contain the average transit time between each pair of nodes.

[1]If the 5th element is not required for the function, it must still be input as 0.

TABLE A-1. Theoretical Distributions in NETSIM II

NETSIM II Code	Function	Arguments		
		a1	b1	c1
1	BETA	Power of x ; $a1 > 0$	Power of (1-x); $b1 > 0$	Random number stream ($1 \leq c1 \leq 10$)
2	BINOMIAL	Number of trials	Probability of success	Random number stream ($1 \leq c1 \leq 10$)
3	ERLANG	Mean	k	Random number stream ($1 \leq c1 \leq 10$)
4	EXPONENTIAL	Mean	Random number stream ($1 \leq b1 \leq 10$)	0
5	GAMMA	Mean	k	Random number stream ($1 \leq c1 \leq 10$)
6	LOG.NORMAL	Mean	Standard deviation	Random number stream ($1 \leq c1 \leq 10$)
7	NORMAL	Mean	Standard deviation	Random number stream ($1 \leq c1 < 10$)
8	POISSON	Mean	Random number stream ($1 \leq b1 < 10$)	0
9	RANDI	Beginning Value	Ending Value	Randon number stream ($1 \leq c1 \leq 10$)
10	UNIFORM	Beginning Value	Ending Value	Random number stream ($1 \leq c1 < 10$)
11	WEIBULL	Scale parameter	Shape parameter	Random number stream ($1 \leq c1 < 10$)

Item Number	Contents
	Note: the user cannot supply both the theoretical function and the INTRALAKE.TRAVEL. TABLE; only one of the choices must be supplied.
	Items B17 through B25 in entirety must be repeated for each reach until all the reaches are exhausted.
B17	ID.REACH
	Identification number of the reach.
B18	LENGTH
	Length of the reach in miles.
B19	PASS.RULE
	The passing rule is 1 if passing is allowed in the reach, 0 otherwise.
B20	RCH.PARA.CODE
	This code is 1 if the reach is part of a parallel routes set, 0 otherwise.
B21	CDF.RTT
	This code is 1 if the reach transit time distribution is specified empirically, 0 if a theoretical function is to be used.
B22	UPSTREAM.NODE
	Upstream node of the reach.
B23	DOWNSTREAM.NODE
	Downstream node of the reach.

Item Number	Contents
B24	Reach transit time distribution Theoretical distribution This specification requires five elements for each direction of travel. The downstream function must precede the upstream function. 1st element = reach identification number 2nd element = NETSIM II code for SIMSCRIPT function (refer to Table A-1) 3-5 elements = parameters[2] of SIMSCRIPT function (refer to Table A-1). Empirical distribution This specification requires two distributions, one for each direction of travel. The distributions must be supplied as pairs of data values where the first of each pair is the probability and the second is the sample value. Input probabilities can be cumulative or individual. At the end of each distribution a blank space must be followed by an asterisk (*). The downstream function must precede the upstream function. Note: the user cannot specify both the theoretical and the empirical functions; only one of the choices must be supplied.
B25	ETT Functions This specification requires four elements for each direction of travel. The downstream function must precede the upstream function. The functions can be given in real format. 1st element = reach identification number 2nd element = reach end node (upstream node for the downstream function and downstream node for the upstream function) 3rd element = statistical coefficient representing the effect of the reach traffic on expected transit time 4th element = statistical coefficient representing the effect of the reach length on expected transit time.

[2] If the 5th element is not required for the function, it must still be input as 0.

Item Number	Contents
	Note: The ETT functions must not be supplied if (1) this is an EDB run, or (2) the reach is not part of a parallel routes set.
	Items B26 through B42 in entirety must be repeated for each lock until all the locks are exhausted.
B26	ID.LOCK Identification number of the lock.
B27	UP.DIR.NODE Upstream node of the lock.
B28	DN.DIR.NODE Downstream node of the lock.
B29	MAXIMUM.VESSEL.LENGTH Maximum vessel length accommodated in lock, expressed in tens of feet.
B30	LOK.PARA.CODE This code is 1 if the lock is part of a parallel routes set, 0 otherwise.
B31	CDF.MOVING This is a code for long entry which is 0 if a theoretical function is to be used. Otherwise, the code must have an integer value between 1 and 10 indicating the empirical distribution that should be used (see Item C5).

Item Number	Contents
B32	CDF.SHORT This is a code for short entry to be supplied as above.
B33	CDF.STERN.CLEAR.TIME This is a code for chamber exit to be supplied as above.
B34	CDF.GATE.TO.CP.TIME This is a code for throat exit to be supplied as above.
B35	CDF.CHAMBER This is a code for chamber cycle to be supplied as above.
B36	MOVING.ADJUSTMENT This is a percentage factor used to adjust an average long entry time of a Class 2 vessel upward (for Class 3 vessels) or downward (for Class 1 vessels). For example, an entry of '15' would indicate that a Class 3 vessel requires 15 percent longer than a Class 2 vessel and a Class 1 vessel requires 15 percent less time than a Class 2 vessel.
B37	SHORT.ADJUSTMENT This is a percentage factor used to adjust short entry time as described above.
B38	STERN.CLEAR.ADJUSTMENT This is a percentage factor used to adjust chamber exit as described above.

Item Number	Contents
B39	GATE.TO.CP.ADJUSTMENT
	This is a percentage factor used to adjust throat exit as described above.
B40	CHAMBER.ADJUSTMENT
	This is a percentage factor used to adjust chamber cycle as described above.
B41	Locking time frequency distributions

These distributions may be specified as empirical or theoretical functions.

Theoretical distribution

This specification requires five elements for each locking time segment. The order of input is as follows:

Long Entry
Short Entry
Chamber Cycle
Chamber Exit
Throat Exit

1st element = lock identification number
2nd element = NETSIM II code for SIMSCRIPT function (refer to Table A-1)
3-5 elements = parameters[3] of SIMSCRIPT function (refer to Table A-1).

Empirical distribution

NETSIM II allows up to ten distributions for each locking time segment. These data are not read at this point in the data deck but rather under Item C5.

Note: The user cannot specify both the theoretical and the empirical functions; only one of the choices must be supplied.

---

[3] If the 5th element is not required for the function, it must still be input as 0.

Item Number	Contents
B42	ETT Functions

This specification requires four elements for each direction of travel. The downstream function must precede the upstream function. The functions can be given in real format.

1st element = lock identification number
2nd element = lock end node (upstream node for the downstream function and downstream node for the upstream function)
3rd element = statistical coefficient representing the effect of the near queue (upstream queue for the downstream function and vice versa) size on expected transit time
4th element = statistical coefficient representing the effect of the far queue (downstream queue for the downstream function and vice versa) size on expected transit time.

Note: The ETT functions must not be supplied if (1) this is an EDB run, or (2) the lock is not part of a parallel routes set.

B43 STAT.ADDITIVE

This is a percentage additive factor used to adjust long entry to reflect chamber entry from a stationary position at queue; set to 0 if not desired. Thus, an entry of '15' would indicate that a long entry from a stationary position consumes 15 percent greater time than a long entry from a moving position.

B44 ARR.SENTRY.PROPORTION

This is a percentage proportion used to adjust long entry to reflect arrival time to a short entry position at lock gates from the lock clear point; set to 0 if not desired. Thus, an entry

Item Number	Contents
	of '60' would indicate that the time to arrive at short entry position from the lock clear point is 60 percent of the time for long entry into chamber.
B45	QUE.SENTRY.ADDITIVE This is a percentage additive factor used to adjust the time segment in Item B44 (arrival time to short entry position) to reflect arrival time to a short entry position from a stationary position at queue; set to 0 if not desired.
B46	PROCESS.ADDITIVE This is a percentage additive factor used to adjust the chamber cycle to reflect a locking process (i.e., a cycle with the chamber occupied, as opposed to an empty cycle); set to 0 if not desired.
C1	TABLE.OF.NEXT.NODES This is a m x n matrix where m is the number of all nodes in the system (i.e., including ports) and n is the number of ports. The table is read row by row and each cell contains the identification number of the next node encountered in traveling from the ith node to the jth port. In the event that parallel routes are present, each route must be given an identification number which is greater than 1000 but less than

Item Number	Contents
	9999 and the entry in the TABLE.OF.NEXT.NODES must be the first of these route identification numbers (the order of the routes is determined by their entry in the PARALLEL.FACILITIES.TABLE).
C2	FACILITIES.ID.TABLE
	This is the lower triangle of a m x m matrix where m is the number of all system nodes. The table is read row by row and each cell contains the identification number of the facility between each pair of consecutive nodes. For each pair of non-consecutive nodes, the entry must be 0.
C3	NO.OF.ROWS
	This is the number of parallel routes in the system.
C4	PARALLEL.FACILITIES.TABLE
	This is a jagged array consisting of two parts. The first part describes each parallel route, row by row.[4] The second part provides the ETT functions for each route.
	Route Description
	The table is read row by row and each row in this first part of the table describes a route which is part of a parallel set. The length of each row is dependent upon the number of nodes present in the route, however, all rows have four common elements as seen below.

[4]All three tables are read row by row and a row is not confined to a single card.

Item Number	Contents

A row consists of the following elements:
1st element = identification number of the route
2nd element = number of routes within a parallel set
3rd element = probability of selecting this route, expressed in percent, for an EDB simulation
4th element = number of nodes on this route
5th element = upstream node of the route
6th element = identification number of the next facility
7th element = next node number
8th element = next facility

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.

last element = downstream node of the route.

Note: the 5th through the last element in each row describe a route completely in terms of links and nodes. Starting with the upstream node, each link and node is listed in order up to and including the downstream node. The user may verify that the upstream and downstream nodes will be common across all routes within a parallel set.

ETT Functions

This specification is given route by route with each route requiring two ETT functions, one for each direction of travel, and each function requiring six elements. The downstream function must precede the upstream function. The functions can be given in real format.
1st element = route identification number
2nd element = end node (upstream node for downstream function and vice versa)
3rd element = statistical coefficient representing the effect of the length of the vessel on expected transit time
4th element = statistical coefficient representing the effect of the draft of the vessel on expected transit time

Item Number	Contents
	5th element = statistical coefficient representing the effect of the route traffic (number of vessels on route) on expected transit time 6th element = statistical coefficient representing the intercept term in the ETT function. Note: The ETT functions (that is, the second part of the PARALLEL.FACILITIES.TABLE) must not be supplied for an EDB run.
C5	Empirical locking time distributions. NETSIM II allows up to ten distributions for each of the five locking time segments. A set of distributions is a collection of five distributions, one for each segment. The distributions are provided by sets, i.e., the user must supply a distribution for each segment in a set before supplying the next set. Each distribution is specified as pairs of data values where the first of each pair is the probability and the second is the sample value. Input probabilities can be cumulative or individual. At the end of each distribution a blank space must be followed by as asterisk (*). Note: These empirical distributions should not be supplied if theoretical functions for locking time segments have been specified in Item B41.
D1	COMMODITY ARRIVALS The commodity arrivals are exogenous events in NETSIM II. As such, they are introduced into the system through the external event notices which have special format.

Item Number	Contents

Card Type	Columns	Description
1	1-11	Characters "COM.ARRIVAL"
	12-20	Simulation time at which the commodities are to arrive in port. This is in real format so that the decimal point must always be present.
2	1-10	Port number into which the commodity is to be introduced
	11-20	Commodity type
	21-30	Destination (port number)
	31-40	Commodity quantity in hundreds of tons.

Note: There will be one type 2[5] card for each port-commodity-destination combination. The type 2 cards must be sequenced in increasing order by commodity type within port number. The last type 2 card must have zeroes in all four fields to signal end of data.

Card Type	Columns	Description
3	1	Character "*" to signal end of event data notices.

This sequence of card types is repeated for every event data notice, i.e., for every commodity arrival notice occurring at a different and higher simulation time. Note that the external event data notices ascend in simulation time. Note also that the commodity arrivals data must be submitted on the COMM.DEVICE (Item A30) unit.

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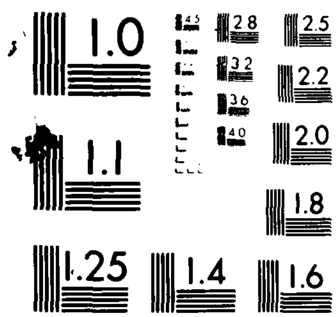
[5] All data in type 2 cards are integer and right justified.

AD-A111 840 PENNSYLVANIA TRANSPORTATION AND TRAFFIC SAFETY CENTER--ETC F/G 13/2
GREAT LAKES-ST. LAWRENCE SEAWAY SIMULATION STUDIES. VOLUME 4. N--ETC(U)
DEC 73 J L CARROLL, S RAO, H G WILSON DACW23-72-C-0066

UNCLASSIFIED TTSC-7319 NL

2 of 3

AD
A111840



MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS 1963-A

Item Number	Contents
E1	VESSEL INTRODUCTIONS

The vessel introductions are also exogenous events in NETSIM II and thus are handled through the external data event notices. In this case, the entire event notice can be fit on one 80-column card with the following format.

Columns	Description
1-12	Characters "CREAT.VESSEL"
13-20	Simulation time at which vessels are to be introduced into the system. This is in real format so that the decimal point must always be present.
	Except as noted, the following fields are integer and right justified.
21-23	Number of the port at which the vessel is to be introduced.
24-27	Vessel length in tens of feet.
28-33	Vessel horsepower in hundreds of horsepower.
34-39	Capacity of vessel in hundreds of tons.
40-44	Unloading rate in hundreds of tons per minute (for self-unloaders only, otherwise 0). (Decimal format).
45-47	Draft of vessel in feet.
48-49	Vessel classification (1 = saltwater; 2 = liquid bulk; 3 = dry bulk).

Item Number	Contents	
	Columns	**Description**
	50-53	Code to indicate backhaul journey (can be set to 0).
	54-59	Commodity tonnage in hundreds of tons (can be set to 0).
	60-61	Commodity type (can be set to 0).
	62-65	Origin (port number).
	66-71	Vessel identification number--vessels should be numbered sequentially beginning with 1.
	75	"*" asterisk.

A card format as indicated above must be prepared for every vessel to be introduced into the system during simulation. These cards must be ascending order ranked by simulation entry time (cc 13-20) and must be submitted on the SHIP.DEVICE (Item A31) unit.

D. OUTPUT

Although the primary output of a NETSIM II simulation run is the event log, a different output is generated for an EDB simulation run. The latter, of course, is used to provide the statistical base for deriving the ETT functions for systems with parallel route options. The third type of output is the commodity inventory level report.

1. EDB Output

The EDB output functionally consists of two parts. The first part generates data for the EDB usage parameters when a vessel arrives at a particular channel choice point in the system. These usage parameters are system conditions such as vessel traffic present at reach and lock facilities on a particular route which is part of the parallel routes set. The second part provides the entry and exit times through each such facility during a vessel's passage on that route. Thus, the actual transit time through a route may be statistically related to the usage parameters, i.e., the systems conditions present when a vessel had initially arrived at the basis of the route.

The output format is as follows (3 I 4 , I 1 , I 4 , I 7, D(7,0)):

			Description	
Item	Column	Format	Part 1	Part 2
1	1-4	I 4	Vessel identification number	Vessel identification number
2	5-8	I 4	Vessel length (in tens of feet)	Vessel length (in tens of feet)
3	9-12	I 4	Current node of vessel	Current node of vessel
4	13	I 1	1	2
5	14-17	I 4	Facility identification number	Facility identification number
6	18-24	I 7	Usage parameter	Entry time
7	25-31	D(7,0)	Usage parameter	Exit time

Note: Item 6 Usage parameter in Part 1 may be one of the following:

<u>For a lock</u>, this parameter is the near queu[illegible]
<u>For a reach</u>, this parameter is the number o[illegible]ls in reach.

Item 7 Usage parameter in Part 1 may be one of the following:

<u>For a lock</u>, this parameter is the far queue size.
<u>For a reach</u>, this parameter is not used and is set to 0.

2. Event Log

The event log consists of a detailed card that records significant attributes for each event that occurs during the simulation and describes

each event by an event code. Each event log record contains eleven elements with the following format (4 I 4 , I 3 , I 1 , I 2 , I 1 , 2 I 4 , D(7,0)).

Item	Column	Format	Description
1	1-4	I 4	Vessel identification number
2	5-8	I 4	Vessel length in tens of feet
3	9-12	I 4	Vessel's current node number
4	13-16	I 4	Vessel's next node number
5	17-19	I 3	Vessel's cargo tonnage in hundreds of tons
6	20	I 1	Commodity type
7	21-22	I 2	Code for dedicated cargo
8	23	I 1	Vessel classification (1 = saltwater; 2 = liquid bulk; 3 = dry bulk)
9	24-27	I 4	Facility identification number
10	28-31	I 4	Event code
11	32-38	D(7,0)	Simulation time

EVENT CODES

The event codes are four digit numerals that completely describe a simulation event in system dynamics. The event codes have been categorized by changes in system status. However, within each category the level of detail in describing system dynamics can enable the user to inspect manually the event log and interpret the simulation. The event code categories are presented first since they form a useful summary of the event log output. This is followed by a description of each event code.

Event Code Categories

Series	Entity	Description
1100	LOCK	Enter queue
1200		Begin entry towards short entry position
1300		Begin entry towards chamber

Series	Entity	Description
1400		Exit queue to begin entry towards chamber
1500		Exit queue to begin entry towards short entry position
1600		Arrive at short entry position
1700		Exit short entry position to begin entry towards chamber
1800		Exit lock
2000		Arrive in chamber
2100		Begin chamber exit
2200		Chamber end cycle--vicinity empty
2300		Chamber end cycle--vicinity not empty
2400		Begin throat exit
3101	LAKE	Enter lake
3102		Exit lake
4101	REACH	Enter reach
4102		Exit reach
5101	WELLAND	Enter queue
5102		Enter locks
5103		Exit locks and enter channels
5104		Exit Welland
9100	PORT	Enter port
9110		Enter cargo queue
9120		Exit cargo queue
9130		Enter berth queue
9140		Exit berth queue
9150		Enter berth
9160		Exit berth

Series	Entity	Description
9170		Exit port
9180		Saltwater vessel departs port for lack of cargo
9190		Bulk vessel dispatched to nearby port to load cargo

Event Codes Description

Notes: The following terminology is used in the event code descriptions.

MOVING.TTT = long entry time

STATIONARY.TTT = long entry time modified by an additive factor (Item B43) to reflect long entry into the chamber from a stationary position at queue.

SHORT.TTT = short entry time.

Code	Description
Decision-triggering event: Arrive at lock	
Resultant action: enter near queue	
1100	Near queue, near throat, chamber are empty. Water level at the moment is correct, but chamber is recycling to the other side.
1101	Near queue is not empty.
1102	Near queue is empty. Near throat is not empty.
1103	Near queue and near throat are empty. Chamber contains a vessel sailing toward arrival vessel.
1104	Near queue and near throat are empty. Chamber contains a vessel sailing in same direction as arrival vessel. Far queue is not empty.
1105	Near queue and near throat are empty; chamber is empty; water level is not okay; far throat is empty; far queue is not empty.

Code	Description
1106	Near queue and near throat are empty; chamber is empty; water level is not okay; far throat contains a vessel sailing in same direction as arrival vessel; far queue is not empty.
1107	Near queue and near throat are empty; chamber is empty; water level is not okay; far throat contains a vessel sailing toward arrival vessel.
1108	Near queue and near throat are empty; chamber contains a vessel sailing in same direction as arrival vessel; far queue is empty; service look-ahead feature is used; far reach contains a vessel which can sail into chamber before arrival vessel; reach vessel uses MOVING.TTT and arrival vessel uses SHORT.TTT for comparison.
1109	Same as 1108 above except that arrival vessel uses MOVING.TTT.
1110	Same as 1108 above except that reach vessel uses STATIONARY.TTT.
1111	Same as 1108 above except that reach vessel uses STATIONARY.TTT and arrival vessel uses MOVING.TTT.
1112	Near queue and near throat are empty; chamber is empty and is not now scheduled for recycling; water level is not okay; far throat contains a vessel sailing in same direction as arrival vessel; service look-ahead feature is used; chamber has not been free long enough to complete recycling before arrival could be in chamber; far reach contains a vessel which can sail into chamber before arrival; reach vessel uses STATIONARY.TTT and arrival vessel uses SHORT.TTT for comparison.
1113	Same as 1112 above except that arrival uses MOVING.TTT.
1114	Same as 1112 above except that reach vessel uses MOVING.TTT.
1115	Same as 1112 above except that reach vessel uses MOVING.TTT and arrival vessel uses MOVING.TTT.
1116	Near queue and near throat are empty; chamber is empty and is not now scheduled for recycling; water level is not okay; far throat is empty; service look-ahead feature is used; chamber has not been free long enough to have now recycled; chamber has not been free long enough to complete recycling before arrival vessel could enter chamber; far reach contains a vessel which can sail into chamber before arrival vessel; reach vessel uses MOVING.TTT and arrival vessel uses SHORT.TTT.
1117	Same as 1116 above except that chamber has been free long enough to complete recycling before arrival could enter chamber, so that arrival vessel uses MOVING.TTT.

Code	Description
1118	Same as 1116 above except that chamber has been free long enough to have now recycled, so that arrival vessel uses MOVING.TTT.

Decision-triggering event: Arrive at lock

Resultant action: Move to short-entry position

1201	Near queue and near throat are empty; chamber contains a vessel sailing in same direction as arrival vessel; far queue is empty; service look-ahead feature is not used; chamber is now recycling but is not able to recycle before vessel would enter chamber using MOVING.TTT.
1202	Near queue, near throat, chamber and far queue are empty; service look-ahead feature is not used; chamber is recycling but will not complete recycle before arrival could move into chamber.
1203	Near queue, near throat, chamber and far queue are empty; service look-ahead feature is not used; chamber is not now recycling; chamber is now scheduled to recycle, but recycling would not be completed before arrival vessel could move into chamber.
1204	Near queue, near throat, chamber, and far queue are empty; service and look-ahead feature is not used; chamber is not now cycling nor is it now scheduled for recycling; chamber has not been free long enough to have completed recycling before arrival vessel could move into chamber.
1205	Near queue, near throat, and far queue are empty; chamber contains a vessel moving in same direction as arrival vessel; service look-ahead feature is used; next reach is empty; chamber would not be able to complete process and recycle before vessel could move into chamber.
1206	Near queue, near throat, chamber, and far queue are empty; service look-ahead feature is used; next reach is empty; chamber is now scheduled for recycling, but it will not be completed before arrival vessel could move into chamber.
1207	Near queue, near throat, chamber, and far queue are empty; service look-ahead feature is used; next reach is empty; chamber is not now scheduled for recycle, nor is it now recycling, chamber has not been free long enough to have completed recycling before arrival vessel could move into chamber.

Code	Description
1208	Near queue, near throat, chamber, and far queue are empty, service look-ahead feature is used; next reach is empty; chamber is now recycling, but will not complete recycle before arrival vessel could move into chamber.
1209	Near queue, near throat, and far queue are empty, chamber contains a vessel moving in same direction as arrival vessel; service look-ahead feature is used; next reach contains a vessel sailing toward arrival vessel; vessel from next reach will arrive at clear point after chamber vessel (therefore uses MOVING.TTT); chamber cannot complete processing and recycle before arrival could have moved into chamber (therefore uses SHORT.TTT); vessel from next reach cannot be in chamber before arrival vessel.
1210	Near queue, near throat, and far queue are empty; chamber contains a vessel moving in same direction as arrival vessel; service look-ahead feature is used; next reach contains a vessel sailing toward arrival vessel; reach vessel will arrive at clear point before chamber vessel (therefore reach vessel uses STATIONARY.TTT); chamber cannot complete processing and recycle before arrival could have moved into chamber (therefore arrival uses SHORT.TTT); reach vessel cannot be in chamber before arrival vessel.
1211	Near queue, near throat, chamber, and far queue are empty; service look-ahead feature is used; next reach contains a vessel sailing toward arrival; chamber is now recycling, but will not finish before arrival could have moved into chamber.
1212	Same as 1211 except that chamber is not now recycling; chamber has been scheduled for recycling, but will not complete recycle before arrival vessel could have moved into chamber.
1213	Near queue, near throat, chamber, and far queue are empty; service look-ahead feature is used; next reach contains a vessel sailing toward arrival vessel; chamber is not now scheduled for recycling nor is it now recycling; far throat contains a vessel sailing in same direction as arrival vessel; reach vessel will arrive at clear point before throat vessel (therefore reach vessel uses STATIONARY.TTT); chamber has not been free long enough to have recycled before arrival vessel could have moved into chamber (therefore arrival vessel uses SHORT.TTT); reach vessel cannot be in chamber before arrival vessel.
1214	Same as 1213 except that reach vessel will not arrive at clear point before throat vessel (therefore reach vessel uses MOVING.TTT).

Code	Description
1215	Near queue, near throat, chamber, far throat, and far queue are empty; service look-ahead feature is used, next reach contains a vessel sailing toward arrival vessel; chamber is not now recycling nor is it now scheduled to recycle; chamber has not been free long enough to have now recycled; chamber has not been free long enough to have recycled before arrival could be in chamber (so arrival uses SHORT.TIT); reach vessel cannot be in chamber before arrival vessel.

Decision-triggering event: Arrive at lock

Resultant action: Move directly into chamber

Code	Description
1301	Near queue and near throat are empty; chamber contains a vessel sailing in same direction as arrival vessel; far queue is empty; service look-ahead feature is not used; chamber is now recycling and will complete cycle before arrival could move into chamber.
1302	Near queue, near throat, chamber, and far queue are empty; far throat is either empty or contains a vessel sailing in same direction as arrival vessel; service look-ahead feature is not used; chamber is now recycling and will complete cycle before arrival vessel could have moved into chamber.
1303	Same as 1302 except that chamber is not now recycling; chamber is now scheduled to recycle and will complete recycling before arrival vessel could have moved into chamber.
1304	Same as 1302 except that chamber is neither now recycling nor scheduled for recycling; chamber has been free long enough to have recycled before arrival vessel could have entered chamber.
1305	Near queue, near throat, and far queue are empty; chamber contains a vessel sailing in same direction as arrival vessel; service look-ahead feature is used; next reach has no vessel sailing toward arrival vessel; chamber is now processing and will be able to complete process and recycle before arrival could move into chamber.
1306	Near queue, near throat, chamber and far queue are empty; look-ahead feature is used; next reach contains no vessel sailing toward arrival vessel; chamber is now scheduled to recycle and will complete recycling before arrival vessel could move into chamber.
1307	Same as 1306 except that chamber is neither now scheduled to recycle nor is now recycling; chamber has been free long enough to have completed recycling before arrival vessel could move into chamber.

Code	Description
1308	Same as 1306 except that chamber is no. now scheduled to recycle but is now recycling and will complete recycling before arrival vessel could move into chamber.
1309	Near queue and near throat are empty; chamber contains a vessel sailing in same direction as arrival vessel, service look-ahead feature is used; next reach contains a vessel sailing toward arrival vessel; reach vessel arrives at clear point after chamber vessel (reach vessel uses MOVING.TTT); chamber is able to complete processing and recycle before arrival vessel could have entered chamber (arrival vessel uses MOVING.TTT); reach vessel cannot be in chamber before arrival vessel.
1310	Near queue and near throat are empty; chamber contains a vessel sailing in same direction as arrival vessel; service look-ahead feature is used; next reach contains a vessel sailing toward arrival vessel; reach vessel arrives at clear point before chamber vessel (reach vessel, therefore, uses STATIONARY.TTT); chamber is able to complete processing and recycle before arrival vessel could have entered chamber (arrival vessel, therefore, uses MOVING.TTT); reach vessel cannot be in chamber before arrival vessel.
1311	Near queue, near throat, chamber and far queue are empty; service look-ahead feature is used; next reach contains a vessel sailing toward arrival; chamber is now recycling and will complete cycle before arrival vessel could have moved into chamber.
1312	Near queue, near throat, chamber and far queue are empty; service look-ahead feature is used; next reach contains a vessel sailing toward arrival; chamber is not now recycling, but is now scheduled for recycling and will complete recycle before arrival vessel could move into chamber.
1313	Near queue, near throat, chamber, and far queue are empty; far throat contains a vessel sailing in same direction as arrival vessel; service look-ahead feature is used; next reach contains a vessel sailing toward arrival vessel; chamber is not now recycling, nor is it now scheduled for recycling, reach vessel arrives at clear point before throat vessel (reach vessel, therefore, uses STATIONARY.TTT); chamber has been free long enough to have recycled before arrival vessel could have entered chamber (arrival vessel, therefore, uses MOVING.TTT); reach vessel cannot be in chamber before arrival vessel.
1314	Same as 1313 except that reach vessel does not arrive at clear point before throat vessel (reach vessel, therefore, uses STATIONARY.TTT).

Code	Description
1315	Near queue, near throat, chamber, far throat, and far queue are empty; service look-ahead feature is used; next reach contains a vessel sailing toward arrival vessel; chamber has not been free long enough to have now recycled, but it has been free long enough to have completed recycling before arrival vessel could have entered chamber; reach vessel cannot be in chamber before arrival vessel.
1316	Near queue, near throat, chamber, far throat, and far queue are empty; service look-ahead feature is used; next reach contains a vessel sailing toward arrival vessel; chamber has been free long enough to have now recycled; reach vessel cannot be in chamber before arrival vessel.
1317	Near queue, near throat, and chamber are empty; water level is okay. Service look-ahead feature is used.

Decision-triggering event: Exit queue

Resultant action: Move into chamber

1401	Chamber is empty. Water level is okay.
1402	Chamber is empty. Water level is not okay. Chamber is now recycling and will complete cycle before vessel could move into chamber.
1403	Chamber is empty. Water level is not okay. Chamber is not now recycling. Chamber is now scheduled to begin recycling and will complete recycling before vessel could move into chamber.

Decision-triggering event: Exit queue

Resultant action: Move into short-entry position

1501	Chamber is not empty.
1502	Chamber is empty. Water level is not okay. Chamber is now recycling but will not complete cycle before vessel could move into chamber.
1503	Chamber is empty. Water level is not okay. Chamber is not now recycling. Chamber is now scheduled to begin recycling but will not complete recycling before vessel could move into chamber.

Code	Description
Decision-triggering event: Move to short-entry position	
1601	Vessel arrives at short-entry position.
Decision-triggering event: End cycle	
Resultant action: Move from short-entry position into chamber	
1701	Chamber recycled empty. Throat to which gates have just opened contains a vessel.
Decision-triggering event: Transit throat	
1801	Vessel exits lock.
2001	Vessel enters chamber.
Decision-triggering event: End cycle	
Resultant action: Move to gates clear point	
2101	Chamber is not empty. Chamber vessel begins chamber exit.
Decision-triggering event: End cycle	
Resultant action: Chamber remains open	
2201	Chamber recycled empty. Throat and queue to which gates have just opened are both empty. Since there is no vessel in the immediate vicinity, the vessel characteristics in the event log record are artificially given zero values.
Decision-triggering event: End cycle	
Resultant action: Chamber remains open	

Code	Description
2301	Chamber recycled empty. Throat to which gates have just opened contains a vessel moving into chamber, i.e., it is not waiting in short-entry position.

Decision-triggering event: Pass through gates clear point

Resultant action: Chamber vessel exits to clearance point

2401	Throat behind chamber vessel is not empty. Therefore, chamber begins to recycle.
2402	Throat behind chamber vessel is empty. Queue in front is not empty.
2403	Throat behind chamber vessel is empty. Queue in front and queue in back are both empty. Service look-ahead feature is not used.
2404	Throat behind chamber vessel is empty. Queue in front is empty. Queue in back is not empty. Service look-ahead feature is used. Next reach contains a vessel sailing toward lock which cannot move into chamber before queued vessel could. Therefore, chamber begins to recycle and queued vessel exits queue.
2405	Throat behind chamber vessel is empty. Queue in front is empty. Queue in back is not empty. Service look-ahead feature is used. Next reach contains a vessel sailing toward lock which could move into chamber before queued vessel could.
2406	Throat behind chamber vessel is empty. Queue in front is empty. Queue in back is not empty. Service look-ahead feature is used. Next reach does not contain a vessel sailing toward lock. Therefore, chamber begins to recycle and queued vessel exits queue.
2407	Throat behind chamber vessel is empty. Queue in front is empty. Queue in back is not empty. Service look-ahead feature is not used. Therefore, chamber begins to recycle and queued vessel exits queue.

3101	Enter lake.
3102	Exit lake.

Code	Description
4101	Enter reach.
4102	Exit reach.
5101	Enter Welland queue.
5102	Enter Welland locks.
5103	Exit Welland locks and enter channels.
5104	Depart Welland.
9100	Enter port.
9110	Enter cargo queue.
9120	Leave cargo queue.
9130	Enter berth queue.
9140	Leave berth queue.
9150	Enter berth.
9160	Leave berth.
9170	Exit port.
9180	Saltwater vessel departs port for lack of cargo.
9190	Bulk vessel dispatched to nearby port to load cargo.

3. Commodity Inventory Level Report

Commodity inventory levels are printed just before each arrival of commodities (overland) into port. Hence, if commodities arrive at seven different times during a 1440 minute day, the commodity levels at each port will be printed out at seven different times for that day. Commodities are classified into three groups: (1) general cargo, (2) liquid bulk and (3) dry bulk. The last includes grain. Inventory levels for each commodity group at each port are reported in two different sets of units:

(1) hundreds of tons,

(2) number of days' influx.

The quantity in (2) is calculated as the quantity in (1) divided by the average daily influx rate of that commodity group into that port (a constant which is supplied by the user).

Due to space constraints for the printed report, certain abbreviations are used to identify the different lines of output. Those abbreviations are defined below.

Abbreviation	Meaning	Description
DR	"dry ratio"	Number of days' influx of dry bulk.
LR	"liquid ratio"	Number of days' influx of liquid bulk.
GR	"general ratio"	Number of days' influx of general cargo.
DT	"dry tonnage"	Hundreds of tons of dry bulk.
LT	"liquid tonnage"	Hundreds of tons of liquid bulk.
GT	"general tonnage"	Hundreds of tons of general cargo.

E. ERROR MESSAGES

This section describes all error messages provided by NETSIM II. The possible reasons for the generation of each message and recommended user action are also discussed.

The user is cautioned at the outset that attempts to pinpoint a particular error to selected input data must be interpreted as answers to the question, "Where should the error search begin?" The real cause of the trouble may actually be elsewhere and it would behoove the user to examine the complete input data deck in each error instance. The descriptions provided below attempt to point at likely underlying error conditions wherever feasible,

but until all possible errors have occurred in every possible way, no such treatment can hope to be exhaustive.

NETSIM II's error messages complement SIMSCRIPT's own error codes listed in reference [12]. Such error conditions as probabilities not summing to 1 in frequency distributions are not checked for in NETSIM II since SIMSCRIPT performs this function quite adequately.

Finally, the user should understand that a run of NETSIM II which does not produce any error messages does not guarantee that the run is correct. It is possible for the user to input an erroneous but logically self-consistent data set, in which case all the sophisticated error diagnostics imaginable would be of little value. Thus, the user is encouraged to scrutinize the results of each run for consistency and face validity.

The error messages are described in subsections below, where the title of each subsection gives the name of the program unit where the errors occurred. Input data mentioned under each error message are given addresses which give their item numbers in Section C of this manual.

1. Routine Movement Controller

-------NETSIM II ERROR MESSAGE 4101-------

VESSEL'S NEXT.FACILITY DDDD DOES NOT MATCH WITH IDENTIFICATION NUMBER OF ANY FACILITY

This message occurs when the identification number of the next facility DDDD through which the vessel must travel, obtained from the FACILITIES.ID. TABLE, does not match the identification number of any facility in the system. The error is most likely to be in the input data for one or all of the following items:

(a) FACILITIES.ID.TABLE (item C2)

(b) HI.PORT (item A6)

(c) HI.LOCK (item A8)

(d) HI.REACH (item A10)

(e) HI.LAKE (item A12)

(f) SWITCH.FOR.WELLAND (item A14).

The user is also referred to NETSIM II's numbering convention explained early in this User Manual.

-------NETSIM II ERROR MESSAGE 4102-------

ENTRY IN TABLE.OF.NEXT.NODES (A , B) EQUAL TO CCCC DOES NOT MATCH WITH ROUTE IDENTIFICATIONS IN FIRST COLUMN OF PARALLEL.FACILITIES.TABLE

The corrective action here involves verifying the validity of the entry CCCC in row A, column B of the TABLE.OF.NEXT.NODES and matching this entry with the first column of the PARALLEL.FACILITIES.TABLE. The user is urged to consult the description for these two tables as well as the numbering convention used in NETSIM II.

-------NETSIM II ERROR MESSAGE 4103-------

ROW A IN THE PARALLEL.FACILITIES.TABLE DOES NOT CORRECTLY MATCH WITH THE VESSELS' CURRENT.NODE BBBB

This message may be due to an error in row A of the PARALLEL.FACILITIES. TABLE. The fifth through the last element in this row must completely describe this route in terms of node, link, node, link, . . . node, starting with the upstream end node of this route and ending with the downstream end node of this route.

The error may also be caused by the fact that BBBB is not a channel choice node, i.e., the node where the channel choice must be made. This error indicates a basic misinterpretation of the input data for the channel choice mechanism in NETSIM II. The user should review the relevant portions of this publication, including the example problem, then reexamine the entire input data set.

-------NETSIM II ERROR MESSAGE 4104-------

VESSEL'S NEXT.FACILITY IS LESS THAN OR EQUAL TO ZERO. VERIFY VESSEL'S NEXT.NODE AAAA IN TABLE.OF.NEXT.NODES (B , C)

If AAAA is the correct entry and if it is greater than 1000, examine the route in the PARALLEL.FACILITIES.TABLE with the identification number AAAA. Otherwise, if the entry is correct and less than 1000, examine the FACILITIES.ID.TABLE.

2. Routine Alternative Selector

-------NETSIM II ERROR MESSAGE 4201-------

VESSEL WITH IDENTIFICATION NUMBER AAAA, LENGTH BBBB AND CURRENT.NODE CCCC IS TOO LONG TO PASS THROUGH LOCKS IN THIS SET.

This error is rather self-explanatory. The vessel's CURRENT.NODE CCCC should identify the location in the system where this error occurred. Corrective action may involve either deleting this vessel from the input deck, changing its length or modifying its itinerary. The error could also be caused by incorrect data for the locks (Item B29).

-------NETSIM II ERROR MESSAGE 4202-------

ROUTE IDENTIFICATION NUMBERS IN PARALLEL.FACILITIES.TABLE INCORRECTLY SUPPLIED

This error results from the fact that the route identification number in part 1 of the PARALLEL.FACILITIES.TABLE must be equal to its identification number given in part 2 (ETT functions) of the table.

-------NETSIM II ERROR MESSAGE 4203-------

LOCK IDENTIFICATION NUMBER GIVEN IN ETT FUNCTIONS FOR LOCK AAAA IS INCONSISTENT WITH OTHER DATA

This error may be due to incorrect data for one or all of the following:

(a) ETT functions for lock AAAA (item B42)

(b) Lock identification numbers (item B26)

(c) LOK.PARA.CODE (item B30).

-------NETSIM II ERROR MESSAGE 4204-------

REACH IDENTIFICATION NUMBER GIVEN IN ETT FUNCTIONS FOR REACH BBBB IS INCONSISTENT WITH OTHER DATA

This error may be due to incorrect data for one or all of the following:

(a) ETT functions for reach BBBB (item B25)

(b) Reach identification number (item B17)

(c) RCH.PARA.CODE (item B20).

-------NETSIM II ERROR MESSAGE 4205-------

PROBABILITIES IN COLUMN 3 OF PARALLEL.FACILITIES.TABLE INCORRECT

3. Routine Stochastic Time Calculations

-------NETSIM II ERROR MESSAGE 5401-------

LOCK IDENTIFICATION NUMBER FOR LOCK AAAA GIVEN IN THEORETICAL FUNCTION FOR LONG ENTRY IS INCONSISTENT WITH OTHER DATA

This error may be due to incorrect data for one or all of the following:

(a) Theoretical function for long entry (item B41)

(b) Lock identification number (item B26)

(c) CDF.MOVING (item B31).

-------NETSIM II ERROR MESSAGE 5402-------

LOCK IDENTIFICATION NUMBER FOR LOCK BBBB GIVEN IN THEORETICAL FUNCTION FOR SHORT ENTRY IS INCONSISTENT WITH OTHER DATA

This error may be due to incorrect data for one or all of the following:

(a) Theoretical function for short entry (item B41)

(b) Lock identification number (item B26)

(c) CDF.SHORT (item B32).

-------NETSIM II ERROR MESSAGE 5403-------

LOCK IDENTIFICATION NUMBER FOR LOCK CCCC GIVEN IN THEORETICAL FUNCTION FOR CHAMBER CYCLE IS INCONSISTENT WITH OTHER DATA

This error may be due to incorrect data for one or all of the following:

(a) Theoretical function for chamber cycle (item B41)

(b) Lock identification number (item B26)

(c) CDF.CHAMBER (item B35).

-------NETSIM II ERROR MESSAGE 5404-------

LOCK IDENTIFICATION NUMBER FOR LOCK DDDD GIVEN IN THEORETICAL FUNCTION FOR CHAMBER EXIT IS INCONSISTENT WITH OTHER DATA

This error may be due to incorrect data for one or all of the following:

(a) Theoretical function for chamber exit (item B41)

(b) Lock identification number (item B26)

(c) CDF.STERN.CLEAR.TIME (item B33).

-------NETSIM II ERROR MESSAGE 5405-------

LOCK IDENTIFICATION NUMBER FOR LOCK EEEE GIVEN IN THEORETICAL FUNCTION FOR THROAT EXIT IS INCONSISTENT WITH OTHER DATA

This error may be due to incorrect data for one or all of the following:

(a) Theoretical function for throat exit (item B41)

(b) Lock identification number (item B26)

(c) CDF.GATE.TO.CP.TIME (item B34).

-------NETSIM II ERROR MESSAGE 5406-------

REACH IDENTIFICATION NUMBER FOR REACH AAAA GIVEN IN THEORETICAL FUNCTION FOR REACH TRANSIT TIME IS INCONSISTENT WITH OTHER DATA

This error may be due to incorrect data for one or all of the following:

(a) Theoretical function for reach transit time (item B24)

(b) Reach identification number (item B17)

(c) CDF.RTT (item B21).

-------NETSIM II ERROR MESSAGE 5407-------

LAKE IDENTIFICATION NUMBER FOR LAKE BBBB GIVEN IN THEORETICAL FUNCTION FOR LAKE TRANSIT TIME IS INCONSISTENT WITH OTHER DATA

This error may be due to incorrect data for one or all of the following:

(a) Theoretical function for lake transit time (item B16)

(b) Lake identification number (item B12)

(c) CDF.LTT (item B15).

4. Routine Query Intralake Travel Table

-------NETSIM II ERROR MESSAGE 5701-------

LAKE NODES FOR LAKE AAAA GIVEN IN INTRALAKE.TRAVEL.TABLE ARE INCONSISTENT WITH OTHER DATA. IN PARTICULAR, CHECK FIRST ROW IN TABLE

If INTRALAKE.TRAVEL.TABLE is correct, check TABLE.OF.NEXT.NODES and FACILITIES.ID.TABLE.

-------NETSIM II ERROR MESSAGE 5702-------

LAKE NODES FOR LAKE BBBB GIVEN IN INTRALAKE.TRAVEL.TABLE ARE INCONSISTENT WITH OTHER DATA. IN PARTICULAR, CHECK FIRST COLUMN IN TABLE

If INTRALAKE.TRAVEL.TABLE is correct, check TABLE.OF.NEXT.NODES and FACILITIES.ID.TABLE.

-------NETSIM II ERROR MESSAGE 5703-------

LAKE IDENTIFICATION NUMBER FOR LAKE CCCC GIVEN IN INTRALAKE.TRAVEL.TABLE IS INCONSISTENT WITH OTHER DATA

If INTRALAKE.TRAVEL.TABLE is correct, check lake identification number (item B12).

5. Routine Exit Queue

-------NETSIM II ERROR MESSAGE 6201-------

EXIT.QUEUE EVENT INVOKED UNDER ERROR CONDITIONS. VESSEL ID AAAA ; LOCK ID BBBB ; SIMULATION TIME CCCCCC.

This error occurs when the chamber is empty but the water level is incorrect and the chamber is neither cycling nor scheduled to recycle. The error may be difficult to trace since any single incorrect item (or presence of extraneous data or deletion of some data) in the input data deck can cause the error. This manual can only suggest a sequential series of steps towards this objective:

(a) Inspect all lock data, but particularly the locking time distributions.

(b) Inspect TABLE.OF.NEXT.NODES.

(c) Inspect FACILITIES.ID.TABLE (and PARALLEL.FACILITIES.TABLE if relevant).

(d) Inspect complete input data deck.

(e) Obtain event log up to program termination and trace simulation events.

(f) Refer to program maintenance.

6. Routine Transit Throat

-------NETSIM II ERROR MESSAGE 6401-------

TRANSIT THROAT EVENT INVOKED UNDER ERROR CONDITIONS. VESSEL ID AAAA ; LOCK ID BBBB ; SIMULATION TIME CCCCCC.

This error occurs when the water level is incorrect but the chamber is neither cycling nor scheduled to recycle. For corrective action, refer to suggestions made above for error message 6201.

-------NETSIM II ERROR MESSAGE 6402-------

TRANSIT.THROAT EVENT EXECUTED PRIOR TO THE END.CYCLE EVENT. VESSEL ID AAAA ; LOCK ID BBBB ; SIMULATION TIME CCCCCC.

The priority order in NETSIM II gives a higher priority to the END.CYCLE event over the TRANSIT.THROAT event if both are scheduled to take place at the same instant. For corrective action, refer to suggestions made above for error message 6201. However, before referring to program maintenance, obtain source decks for the preamble and the TRANSIT.THROAT routine, compile them to obtain new object decks and rerun the simulation.

7. Routine Breeze Through Welland

-------NETSIM II ERROR MESSAGE 6701-------

VESSEL AAAA OF LENGTH BBBB IS TOO LONG TO GO THROUGH THE WELLAND CANAL

Corrective action for this error may involve one of the following courses:

(a) Delete vessel from input data deck

(b) Modify length of vessel

(c) Modify this routine.

APPENDIX B

EXAMPLE PROBLEM

A. INTRODUCTION

This appendix presents one form of a sample problem that was used largely for testing the simulation package. In the interest of reducing data requirements and saving on computer run costs, it was decided not to use the entire Great Lakes-St. Lawrence Waterway System (GL-SLS). Instead, a reduced hypothetical navigation system which resembles the GL-SLS in many respects was chosen. That system is shown in Figure B-1. Figure B-1 also includes the facility numbers which were assigned.

B. INPUT DATA

The main input data stream is displayed, in sequence, in Figures B-2 through B-8. Following are explanations of those data.

Figure B-2 contains what may be classified as run parameters. Each number will be explained individually. Variable names are those used in the User Manual (Appendix A).

30000	SEASON.LENGTH	This run will simulate 30000 minutes (about 21 days).
0	EDB.CODE	This is not an EDB run.
0	LOOK.AHEAD.CODE	The service look ahead feature will not be used.
0	PARA.CODE	There are no parallel route options.
9	TAPE.DRIVE	The event log will be written to unit 9.
12	HI.PORT	The highest numbered port is 12. This is the "Atlantic Port."
12	N.PORT	There are 12 ports.
15	HI.LOCK	The highest numbered lock is 15.

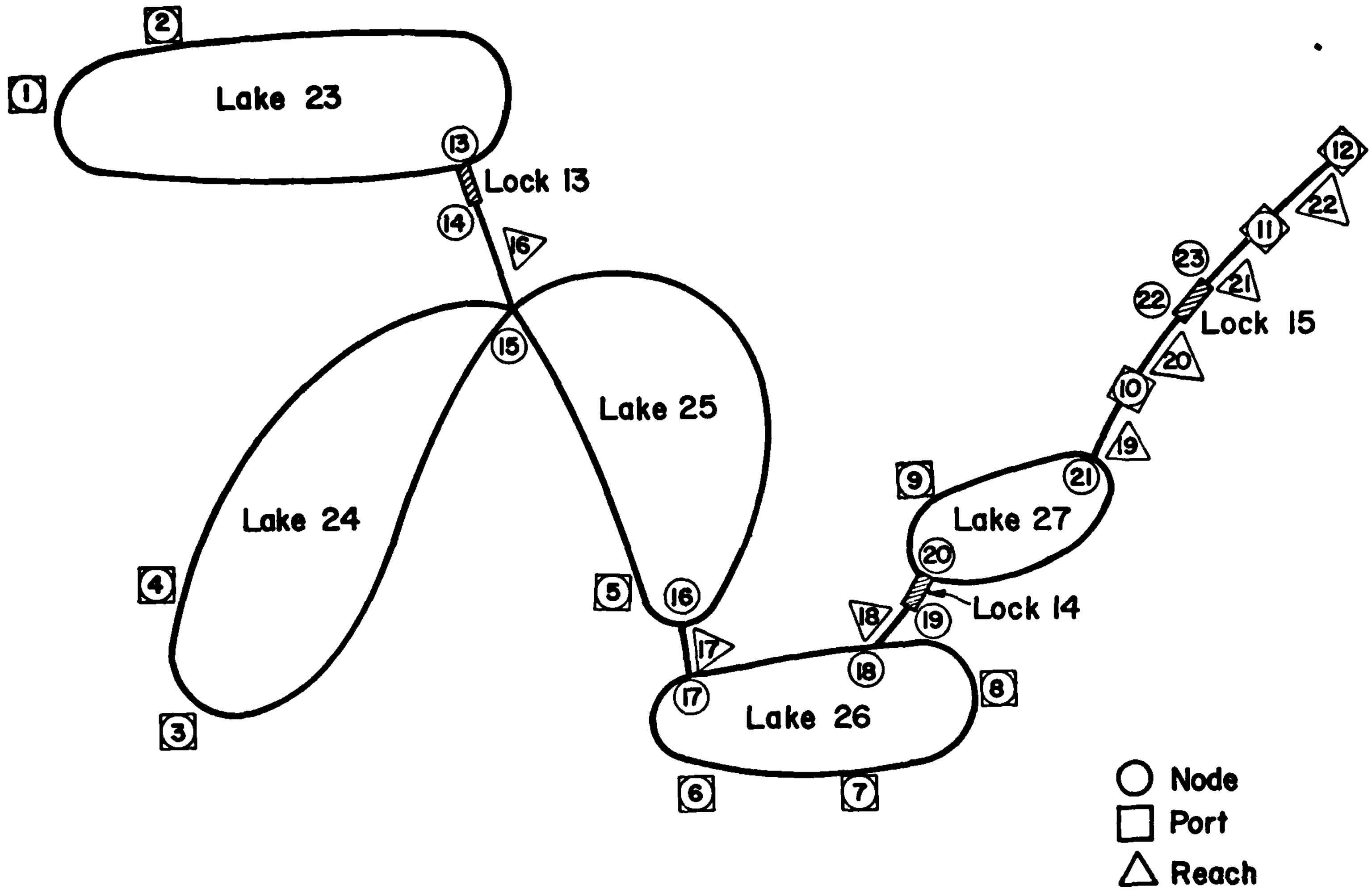


Figure B-1. Example Navigation System

30000	0	0	0		
9	12	12			
15	3	22	7	27	5
0	23	5	1		
2	2	4	12	1	2
3	0	8	10	10	5
7	8	40	73	11	12
133.4	112.0				
93.4	87.5				
0.95					
1	80	80			
4	3	2	2	1	

Figure B-2. Run Parameters

3	N.LOCK	There are 3 locks.
22	HI.REACH	The highest numbered reach is 22.
7	N.REACH	There are 7 reaches.
27	HI.LAKE	The highest numbered lake is 27.
5	N.LAKE	There are 5 lakes.
0	SWITCH.FOR.WELLAND	The system contains no "Welland."
23	NO.OF.NODES	There are 23 nodes in the system.
5	GEN.INDEX	Commodity type 5 is general cargo.
1	LIQ.INDEX	Commodity type 1 is liquid bulk.
2	GRN.INDEX	Commodity type 2 is grain.
2 4	DRY.LO DRY.HI	Commodity types 2 through 4 are dry bulk cargoes.
12	ATLANTIC.PORT	Port 12 represents the world beyond the mouth of the St. Lawrence River. This should always be the same as HI.PORT.
1	STREAM	Random number stream 1 will be used in a random mechanism involved with choosing saltwater vessels' cargoes.
2	STREAM1	Random number stream 2 will be used for making empty backhaul decisions.
3	STREAM2	Random number stream 3 will be used to calculate the random element of time in berth.
0	G.C.SWITCH	Saltwater vessels are not required to change berths between unloading and loading general cargo.
8	ERIE.EAST	The highest numbered port above the Welland Canal is 8.
10	DR.MAX	If more than 10 days' influx of dry bulk cargo has accumulated at any port, dry bulk vessels which are dispatched from that port loaded will be marked for empty backhaul.
10	LR.MAX	As in the previous item, only for liquid commodities and vessels.

5	NUM.COMMOD	There are 5 commodities. This number should always be the same as GEN.INDEX.
7	COMM.DEVICE	COM.ARRIVAL external event notices will be read from unit 7.
8	SHIP.DEVICE	CREAT.VESSEL external event notices will be read from unit 8.
40	1.CLASS	The first vessel class ranges from 0 to 400 feet in length.
73	2.CLASS	The second vessel class ranges from 410 to 730 feet in length. The third class is 740 feet and over.
11	IT.DEVICE	Itineraries for saltwater vessels are read from unit 11.
12	RAT.UNIT	The commodity inventory report will be printed on unit 12.
133.4	LK.2500HP.LESS.ADJ	Vessels of 2500 horsepower or less will take 33.4% longer to travel between 2 points on a lake than will vessels with 4001 through 5000 horsepower.
112.0	LK.4000HP.OR.LESS.ADJ	Vessels between 2501 and 4000 horsepower require 12% longer for lake travel than the 4001 through 5000 horsepower class.
93.4	LK.5000HP.OR.GRT.ADJ	Vessels between 5001 and 8000 horsepower require only 93.4% as long for lake travel as the 4001 through 5000 horsepower class.
87.5	LK.8000HP.OR.GRT.ADJ	Vessels of over 8000 horsepower require only 87.5% as long for lake travel as the 4001 through 5000 horsepower class.
0.95	VSL.LDG.FACTOR	The load limit for any vessel is 95% of the stated capacity. (The capacity is stated in the CREAT.VESSEL external event notice.)
1	MIN.CARG(1)	The minimum amount of general cargo which qualifies for loading on a vessel is 100 tons.
80	MIN.CARG(2)	The minimum amount of liquid bulk cargo which qualifies for loading onto a vessel is 8000 tons. Note that this means 8000 tons all bound for the same destination.

80	MIN.CARG(3)	As above, but for dry bulk commodities.
4	BER.CONV(1)	Commodity type 1 requires berth type 4 (liquid).
3	BER.CONV(2)	Commodity type 2 requires berth type 3 (grain).
2 2	BER.CONV(3) BER.CONV(4)	Commodity types 3 and 4 require berth type 2 (dry bulk).
1	BER.CONV(5)	Commodity type 5 requires berth type 1 (general cargo).

Figure B-3 contains all of the port data. The values for the first port (the first 8 lines of data) will be explained. Successive sets of data simply repeat the same format.

First Line:

1	Port number 1
30	A minimum of 30 minutes is required for a vessel to enter and leave the port.
240	24000 tons of dry bulk commodities arrive (overland) into port each day.
40	4000 tons of liquid bulk arrive each day.
8	800 tons of general cargo arrive each day.
27	The minimum depth of the port is 27 feet.
1	1 port is designated as a "nearby port," at which cargo may be sought if none is available here (in port 1).

Second Line:

2	The nearby port is port number 2.

Third Line:

1	Port number 1.
.01	The unloading rate for general cargo (at port 1) is 1 ton per minute.

1		30		240		40	8	27	1
2									
1		.01		.14		1.8	2.0		
1		.01		.25		1.8	2.0		
1		15		15		15	15		
1		25		25					
1		2		10		3	2		
1	.95	.95	.95	.95	.95				
2		30		200		40	0	27	1
1									
2		.01		.14		1.8	2.0		
2		.01		.25		1.8	2.0		
2		15		15		15	15		
2		25		25					
2		1		6		2	1		
2	.95	.95	.95	.95	.95				
3		40		200		120	40	27	1
4									
3		.01		.14		1.8	2.0		
3		.01		.25		1.8	2.0		
3		15		15		15	15		
3		25		25					
3		10		6		3	2		
3	.95	.95	.95	.95	.95				
4		30		160		120	16	27	1
3									
4		.01		.14		1.8	2.0		
4		.01		.25		1.8	2.0		
4		15		15		15	15		
4		25		25					
4		4		4		3	1		
4	.95	.95	.95	.95	.95				
5		35		120		80	24	27	2
4		6							
5		.01		.14		1.8	2.0		
5		.01		.25		1.8	2.0		
5		15		15		15	15		
5		25		25					
5		6		5		1	2		
5	.95	.95	.95	.95	.95				
6		25		160		120	16	27	2
5		7							
6		.01		.14		1.8	2.0		
6		.01		.25		1.8	2.0		
6		15		15		15	15		
6		25		25					
6		6		5		1	2		
6	.95	.95	.95	.95	.95				

Figure B-3. Port Data

7		40		200		120	32	27	2
6		8							
7		.01		.14		1.8	2.0		
7		.01		.25		1.8	2.0		
7		15		15		15	15		
7		25		25					
7		8		7		3	3		
7	.95	.95	.95	.95	.95				
8		30		120		40	8	27	1
7									
8		.01		.14		1.8	2.0		
8		.01		.25		1.8	2.0		
8		15		15		15	15		
8		25		25					
8		3		6		1	1		
8	.95	.95	.95	.95	.95				
9		30		200		160	80	27	1
10									
9		.01		.14		1.8	2.0		
9		.01		.25		1.8	2.0		
9		15		15		15	15		
9		25		25					
9		10		6		3	1		
9	.95	.95	.95	.95	.95				
10		50		160		80	80	27	1
9									
10		.01		.14		1.8	2.0		
10		.01		.25		1.8	2.0		
10		15		15		15	15		
10		25		25					
10		10		7		4	2		
10	.95	.95	.95	.95	.95				
11		40		120		80	60	27	0
11		.01		.14		1.8	2.0		
11		.01		.25		1.8	2.0		
11		15		15		15	15		
11		25		25					
11		10		4		2	1		
11	.95	.95	.95	.95	.95				
12		00		0		0	0	27	0
12		.01		.14		1.8	2.0		
12		.01		.25		1.8	2.0		
12		0		0		0	0		
12		25		25					
12		0		0		0	0		
12	.95	.95	.95	.95	.95				

Figure B-3 (continued).

.14	The unloading rate for dry bulk cargo is 14 tons per minute.
1.8	The unloading rate for grain is 180 tons per minute.
2.0	The unloading rate for liquid cargoes is 200 tons per minute.

<u>Fourth Line</u>:

Loading rates for general cargo, dry bulk, grain and liquid in the same format as the unloading rates.

<u>Fifth Line</u>:

1	Port number 1.
15 15 15 15	The mean random component of turnaround time in port is 15 minutes for each of the 4 berth types. Fifteen minutes is also the standard deviation of this component.

<u>Sixth Line</u>:

1	Port number 1.
25	If more than 25 dry bulk vessels are awaiting cargo at this port, any other dry bulk vessel that has just completed unloading will be sent back to its origin empty.
25	Same as above, but for liquid bulk vessels.

<u>Seventh Line</u>:

1	Port number 1.
2	This port has 2 general cargo berths.
10	This port has 10 dry bulk berths.
3	This port has 3 grain berths.
2	This port has 2 liquid bulk berths.

<u>Eighth Line</u>:

1	Port number 1.

0.95	Any bulk vessel that (1) has just finished loading commodity 1, and (2) has not been marked for empty backhaul due to cargo accumulation in this port, has a .95 probability of being marked for empty backhaul. If it is so marked, it will return to this port empty after unloading at its destination port.
0.95 0.95 0.95 0.95	Same as above for commodities 2, 3, 4 and 5.

Figure B-4 contains the lake data. The data for the first lake (first 5 lines) will be explained.

<u>First Line</u>:

23	ID.LAKE	Lake number 23.
3	NUM.OF.LAKE.NODES	There are 3 nodes on this lake.
0	LAK.PARA.CODE	This lake is not part of a parallel route set.
1	CDF.LTT	The lake transit time distribution is specified empirically.

<u>Second Line</u>:

23	Lake number 23.
1 2 13	The three nodes on lake number 23 are numbered 1, 2 and 13.

<u>Third Line</u>:

1	Travel times from node 1 are to follow.
0	Travel time from node 1 to node 1 is zero.
400	Travel time from node 1 to node 2 is 400 minutes (for vessel with 4000-5000 horsepower).

23	3	0	1		
23	1	2	13		
1	0	400	960		
2	400	0	600		
13	960	600	0		
24	3	0	1		
24	15	4	3		
15	0	900	1000		
4	900	0	240		
3	1000	240	0		
25	3	0	1		
25	15	5	16		
15	0	800	920		
5	800	0	200		
16	920	200	0		
26	5	0	1		
26	17	6	7	8	18
17	0	180	600	800	840
6	180	0	440	640	700
7	600	440	0	400	460
8	800	640	400	0	140
18	840	700	460	140	0
27	3	0	1		
27	20	9	21		
20	0	180	700		
9	180	0	600		
21	180	600	0		

Figure B-4. Lake Data

960	Travel time from node 1 to node 13 is 960 minutes.

Fourth Line:

2	Travel times from node 2 are to follow.
400	Travel time fron node 2 to node 1 is 400 minutes.
0	Travel time from node 2 to node 2 is zero.
600	Travel time from node 2 to node 13 is 600 minutes.

Fifth Line:

As above, travel times from node 13 to other nodes.

The remaining data in Figure B-4 are in the above format, for lakes 24, 25, 26 and 27.

Figure B-5 contains the reach data. The first three lines are for reach number 16.

First Line:

16	ID.REACH	Reach number 16.
20	LENGTH	This reach is 20 miles long.
1	PASS.RULE	Passing is allowed.
0	RCH.PARA.CODE	This reach is not part of a parallel route set.
0	CDF.RTT	A theoretical function will be used to calculate reach transit time.
14	UPSTREAM.NODE	Node 14 is the upstream node of this reach.
15	DOWNSTREAM.NODE	Node 15 is the downstream node of this reach.

16	20	1	0	0	14	15
16	10	50	80	4		
16	10	60	90	4		
17	15	0	0	0	16	17
17	10	100	150	5		
17	10	100	150	5		
18	20	1	0	0	18	19
18	10	400	800	6		
18	10	400	800	6		
19	50	1	0	0	21	10
19	10	600	900	7		
19	10	600	900	7		
20	40	1	0	0	10	22
20	10	500	800	7		
20	10	500	800	7		
21	20	1	0	0	23	11
21	10	300	500	8		
21	10	300	500	8		
22	50	1	0	0	11	12
22	10	600	800	8		
22	10	600	800	8		

Figure B-5. Reach Data

Second Line:

16	Theoretical distribution parameters for downstream travel time through reach 16 are to follow.
10	Uniform distribution.
50 80	Travel times will be chosen from a uniform distribution between 50 and 80 minutes.
4	Use random number stream 4 for this sampling.

Third Line:

16	Theoretical distribution parameters for upstream travel time through reach 16 are to follow.
10	Uniform distribution.
60 90	Travel times will be chosen from a uniform distribution between 60 and 90 minutes.
4	Use random number stream 4 for this sampling.

The remainder of Figure B-5 is data for reaches 17 through 22 in the same format.

Figure B-6 contains the lock data. The first six lines are for lock number 13.

First Line:

13	ID.LOCK	Lock number 13.
13	UP.DIR.NODE	The upstream node of this lock is node number 13.
14	DN.DIR.NODE	The downstream node of this lock is node number 14.
120	MAXIMUM.VESSEL.LENGTH	Vessels over 1200 feet in length cannot pass through this lock.
0	LOK.PARA.CODE	This lock is not part of a parallel route set.
0	CDF.MOVING	A theoretical distribution function will be used for long entry time.

```
13 13 14 120  0 0 0 0 0 0 10 15 10 15 10
13  7 20. 5. 4
13  7 10. 2.5 4
13  7 12. 4. 4
13  7 6. 2. 4
13  7 8. 2.3 4
14 19 20 120  0 0 0 0 0 0 10 15 10 15 10
14  7 20. 5. 4
14  7 10. 2.5 4
14  7 12. 4. 4
14  7 6. 2. 4
14  7 8. 2.3 4
15 22 23 120  0 0 0 0 0 0 10 15 10 15 10
15  7 20. 5. 4
15  7 10. 2.5 4
15  7 12. 4. 4
15  7 6. 2. 4
15  7 8. 2.3 4
15 60 10 15
```

Figure B-6. Lock Data

0	CDF.SHORT	Each of the 4 remaining segments
0	CDF.STERN.CLEAR.TIME	of locking time will have a
0	CDF.GATE.TO.CP.TIME	theoretical distribution.
0	CDF.CHAMBER	
10	MOVING.ADJUSTMENT	Class 1 vessels (under 400 feet) require 10% less time for a moving entry than do class 2 vessels. Class 3 vessels require 10% longer than class 2.
15	SHORT.ADJUSTMENT	Class 1 and class 3 vessels require 15% less and 15% more time, respectively, than class 2 vessels for a short entry.
10	STERN.CLEAR.ADJUSTMENT	Similarly for chamber exit,
15	GATE.TO.CP.ADJUSTMENT	throat exit and chamber
10	CHAMBER.ADJUSTMENT	cycle times.

<u>Second Line:</u>

13	Lock number 13.
7	Normal distribution will be used for long entry time.
20	The mean of the normal distribution is 20 minutes.
5	The standard deviation of the normal distribution is 5 minutes.
4	Random sampling from this distribution will be done with random number stream 4.

<u>Third through Sixth Lines:</u>

Theoretical distribution parameters, in above format, for short entry, chamber cycle, chamber exit and throat exit times.

The seventh through eighteenth lines in Figure B-6 are for locks 14 and 15. The nineteenth (last) line contains four parameters that apply to all of the locks.

Nineteenth Line:

15	STAT.ADDITIVE	Long entry from a stationary point in a queue requires 15% longer than a moving long entry.
60	ARR.SENTRY.PROPORTION	Time required to move from the clear point to a short entry position is 60% of total (moving) long entry time.
10	QUE.SENTRY.ADDITIVE	Time required to move to a short entry position requires 10% longer if the movement begins from a stationary point in a queue.
15	PROCESS.ADDITIVE	Chamber cycle time is 15% longer when the chamber is occupied than when it is empty.

Figure B-7 contains the table of next nodes. Note that the columns correspond to the port numbers, 1 through 12, and the rows correspond to the node numbers, 1 through 23 (the first 12 of which are ports), although these column and row labels have not been punched explicitly.

Consider, for example, the fourth row in the table. The first entry is a 15, indicating that in going from node 4 to node 1, the next node encountered is node 15. The user should verify this on the navigation system diagram (Figure B-1). The third entry in the fourth row is a 3, indicating that in going from node 4 to node 3 the next node is node 3; in other words there are no intermediate nodes. The fourth number in the fourth row is a zero; going from node 4 to node 4 is meaningless.

Figure B-8 contains the facilities Id table. Note that this is a lower half matrix without the main diagonal. Hence the rows correspond to nodes 2 through 23 and the columns correspond to nodes 1 through 22. The first entry in the table, 23, indicates that in going from node 2 to node 1 the next facility is 23. The sixth (last) number in the sixth row is a 26. This indicates that in going from node 7 to node 6 (or vice versa) the next facility is number 26. The multitude of zeroes in the table are for pairs of nodes that are not consecutive.

0	2	13	13	13	13	13	13	13	13	13	13
1	0	13	13	13	13	13	13	13	13	13	13
15	15	0	4	15	15	15	15	15	15	15	15
15	15	3	0	15	15	15	15	15	15	15	15
15	15	15	15	0	16	16	16	16	16	16	16
17	17	17	17	17	0	7	8	18	18	18	18
17	17	17	17	17	6	0	8	18	18	18	18
17	17	17	17	17	6	7	0	18	18	18	18
20	20	20	20	20	20	20	20	00	21	21	21
21	21	21	21	21	21	21	21	21	0	22	22
23	23	23	23	23	23	23	23	23	23	0	12
11	11	11	11	11	11	11	11	11	11	11	00
1	2	14	14	14	14	14	14	14	14	14	14
13	13	15	15	15	15	15	15	15	15	15	15
14	14	3	4	5	16	16	16	16	16	16	16
15	15	15	15	5	17	17	17	17	17	17	17
16	16	16	16	16	6	7	8	18	18	18	18
17	17	17	17	17	6	7	8	19	19	19	19
18	18	18	18	18	18	18	18	20	20	20	20
19	19	19	19	19	19	19	19	9	21	21	21
20	20	20	20	20	20	20	20	9	10	10	10
10	10	10	10	10	10	10	10	10	10	23	23
22	22	22	22	22	22	22	22	22	22	11	11

Figure B-7. Table of Next Nodes

23																					
0	0																				
0	0	24																			
0	0	0	0																		
0	0	0	0	0																	
0	0	0	0	0	26																
0	0	0	0	0	26	26															
0	0	0	0	0	0	0	0														
0	0	0	0	0	0	0	0	0													
0	0	0	0	0	0	0	0	0	0												
0	0	0	0	0	0	0	0	0	0	22											
23	23	0	0	0	0	0	0	0	0	0	0										
0	0	0	0	0	0	0	0	0	0	0	0	13									
0	0	24	24	25	0	00	0	0	0	0	0	0	16								
0	0	0	0	25	0	0	0	0	0	0	0	0	0	25							
0	0	0	0	0	26	26	26	0	0	0	0	0	0	0	17						
0	0	0	0	0	26	26	26	0	0	0	0	0	0	0	0	26					
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18				
0	0	0	0	0	0	0	0	27	0	0	0	0	0	0	0	0	0	14			
0	0	0	0	0	0	0	0	27	19	0	0	0	0	0	0	0	0	0	27		
0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	21	0	0	0	0	0	0	0	0	0	0	15

Figure B-8. Facilities ID Table

This appendix has presented an example of a main input data stream. A run of NETSIM II also requires (1) saltwater vessel itineraries, (2) CREAT.VESSEL external event notices and (3) COM.ARRIVAL external event notices on separate input files. Part III of this report documents three support programs which have been provided to facilitate preparation of these three kinds of inputs. The complete data streams on these three files are too voluminous to be reproduced here. Sample records, however, are shown in Figure B-9.

Figure B-9(a) shows a sample saltwater vessel itinerary record. Note that this particular record consists of two cards. The first number, 6, indicates that there are six stops on the itinerary. The order of the ports of call is 7, 3, 9, 10, 11, 12. The last number, 12, is the "Atlantic Port" at which the vessel will leave the system. On this itinerary the vessel will unload 30% of its cargo at port 7 and then load cargo amounting to 25% of its capacity before leaving port 7. At port 9 it will unload 13.3% and load 16.7%, and so on.

Figure B-9(b) is a sample CREAT.VESSEL external event notice. The numbers are interpreted as follows:

7200	The vessel is to be introduced into the system at simulation time 7200.
12	The vessel is to be introduced into port 12 (the Atlantic Port).
50	Vessel length is 500 feet.
50	The vessel has 5000 horsepower.
150	Vessel cargo capacity is 15000 tons.
0	Not a self-unloader.
20	Loaded draft is 20 feet.
1	Vessel type 1 (saltwater).

```
6  7 0.250 0.300  3 0.250 0.300  9 0.167 0.133 10 0.167 0.133
  11 0.167 0.133 12 0.0   0.0
```

(a) Saltwater vessel itinerary record.

```
CREAT.VESSEL   7200. 12  50    50   150    0 20 1  0     0 0   0   104   *
```

(b) CREAT.VESSEL external event notice.

```
COM.ARRIVAL
       1      1      3      16
```

(c) First two cards of a COM.ARRIVAL event notice.

Figure B-9. Sample External Event Notice Records

0	Empty backhaul code (of little interest to the user).
0	Cargo tonnage. NETSIM II uses this parameter to keep track of the amount of cargo currently being carried.
0	Cargo type. NETSIM II will adjust this parameter. The user can leave it at zero.
0	Vessel origin. Again, this parameter is adjusted by NETSIM II as needed.
104	Vessel number 104.

Figure B-9(c) contains the first two cards of a COM.ARRIVAL external event notice. Beginning on the second card:

1	This item of cargo will originate in port 1.
1	This cargo is commodity type 1.
3	The destination of the cargo is port 3.
16	The amount of commodity is 1600 tons.

Many cards in this same format would be included in a single COM.ARRIVAL notice. One card is required for each origin-commodity-destination combination.

PART II

PROSIM : A SIMULATION PROCESSOR FOR NETSIM II

CHAPTER 6. INTRODUCTION TO PROSIM

The Pennsylvania Transportation and Traffic Safety Center has developed a computer simulation package for the analysis of the Great Lakes-St. Lawrence Waterway System[1]. This simulation package is composed of three parts. The first section is the simulation program (NETSIM II)[2], which produces as output an event log describing each event that occurred during the simulation. This event log is then processed by a report generation program (PROSIM). The third part consists of four support programs which perform auxiliary functions such as specific data preparations for NETSIM II[3]. This chapter describes key features of the PROSIM program and succeeding chapters delve into its input, operations and output capabilities. A PROSIM User Manual is also provided in Appendix C.

A. PROSIM OBJECTIVES

The primary purpose of PROSIM is to remove the statistical output generation burden from NETSIM II. Main features dictating the separation of statistical processing from the actual simulation program were:

1. the critical need to reduce space requirements for the simulation program;
2. ease of debugging and error detection;

---

[1] Volume 3 in this series describes the rationale for and the background behind this model development effort.

[2] The NETSIM II program is treated in Part I of this publication.

[3] The support programs are documented in Part III of this publication.

3. the ability to tailor the output to fill the needs of the user without conducting several reruns of the time-consuming simulation phase; and
4. the creation of a permanent, detailed record of the simulation for calibration and operation analysis apart from the aggregate statistical reports.

These desirable features were not obtained without some sacrifice in time requirements. Clearly, some duplicative effort exists between NETSIM II and PROSIM with regard to input-output processing and program structure. Nevertheless, the flexibility afforded by the separation of statistical processing from the simulation phase is deemed to be of sufficient merit to warrant this structure.

B. THE PROSIM PROGRAM

The PROSIM program requires two classes of input data:

(1) run parameters

(2) NETSIM II event log.

Chapter 7 elaborates on these data items.

The main operations carried out by the PROSIM program are interpretation of the event log and the collection of the relevant statistical data for generating the output tables. In all, PROSIM produces 15 tables of performance summaries for the fixed facilities in the system. The following list summarizes the contents of these tables:

(1) the number of ships originating and terminating at each port by type as well as the tonnage, loading and unloading times, berth delays, cargo delays and queue lengths by cargo type;

(2) at each lock in the simulated system, the total vessels processed, tonnage, delays, transit times, queue lengths and utilization rates by direction and vessel type;

(3) traffic summaries and transit times for reaches and lakes.

These output tables can be printed both at intervals and at the end of the simulation. In addition to these printouts, PROSIM can also punch selected statistics for further tests of statistical inference.

C. PROGRAM CAPABILITIES

PROSIM currently exists as a set of subroutines written in SIMSCRIPT II.5 for the IBM 370/165 computer. Space requirements for this program are outlined in Appendix D. A modular design was used in constructing the program, thus modifications to effect further statistical refinement or generate additional output such as histograms, time flow charts, etc., would be relatively simple to implement.

CHAPTER 7. INPUT

This chapter describes and discusses the input data required by PROSIM. Detailed card format specifications may be found in Appendix C, PROSIM User Manual.

PROSIM requires 2 classes of input data:

(1) Run parameters;

(2) NETSIM II event log.

Each of these classes is treated in the following sections.

A. RUN PARAMETERS

This class of data includes the following items:

(1) system size parameters

(2) total simulation run time in minutes

(3) length of warm-up periods in minutes

(4) intermediate printout interval in minutes

(5) input/output devices

(6) selection of the output tables to be generated

(7) vessel classification parameters.

Item 1 includes specification of the number of entities in the system (ports, locks, vessels, etc.) and pointers to the numbering scheme for these entities. These data allow PROSIM to construct its entity structures.

Item 2 controls the total simulation run time and must be large enough to provide the user with a steady state simulation for the desired period. Thus, if it is desired to simulate a period of 30 days with a warm-up time of 4 days, the simulation run time T should be set at

$$T = 1440 \times 34$$

where the warm-up time has been added to the desired simulation period.

Item 3 specifies two warm-up periods, one for ports and the other for the rest of the fixed facilities such as locks, reaches, lakes, etc. The reason for this dichotomy is that locks and reaches start the simulation in an empty period whereas ports do not. Although two separate warm-up periods are allowed, they should be set to the same value (for ease of output interpretation) until and unless experience dictates otherwise. If they have different values, the larger value should be used in the calculation of the total run time above.

Item 4 provides the interval between intermediate printouts. The first intermediate output is printed at a simulation time equal to the warm-up time plus the interval time. Subsequent outputs are generated at succeeding intervals until the simulation time equals the total run time at which point the final output is printed. A run with an interval of 10,000 minutes, warm-up time of 5,000 minutes and a total run time of 40,000 minutes will generate output at the following times:

Time	Output Type
15,000 min.	Intermediate
25,000	Intermediate
35,000	Intermediate
40,000	Final.

If intermediate output is not desired, the interval value should be set equal to the total run time.

Items 5 and 6 specify input/output devices and output options. The output options dictate which of PROSIM's 15 tables are to be printed during intermediate printouts. All of the output tables are printed at the end of the simulation, however.

Item 7 provides length limits for determining vessel categories. As in NETSIM II, PROSIM allows up to three vessel categories.

B. NETSIM II EVENT LOG

The NETSIM II event log is the primary output of NETSIM II and the main input into PROSIM. The event log is a description of all events that occurred during the simulation and lists the time of occurrence, vessel identification, vessel attributes such as length, current node, next node, cargo tonnage, commodity type and classification, facility identification and an event code[1] which specifies the nature of the event. The event log will normally be input to PROSIM through an auxiliary unit such as a tape file for ease of handling.

[1] A complete des :tion and interpretation of the event codes is given in Appendix A, :t I of this publication.

CHAPTER 8. OPERATIONS

A. OVERVIEW

The conceptual design of PROSIM is rather straightforward since its main function is merely to access the NETSIM II event log and gather relevant statistics for output printouts. To facilitate this function, PROSIM's entity structure has been constructed very similarly to that of NETSIM II. There are two main differences, however:

(1) Many entity attributes, variables and arrays in NETSIM II are not needed in PROSIM. Instead, PROSIM is saturated with statistic-gathering SIMSCRIPT statements which provide it automatically with routines to calculate such parameters as the mean, sum and standard deviation.

(2) PROSIM does not contain any set structures, hence does not contain owner-member relationships. This is because PROSIM does not conduct any vessel processing (as does NETSIM II) but simply gathers information from the event log.

B. PROGRAM STRUCTURE

PROSIM begins event log processing by referencing the initialization routine which reads all the input data and constructs PROSIM's entity structures. Upon completion of its task, the initialization routine is released to conserve space.

PROSIM next references the event log processor routine which controls the program flow. Its main function is to read and interpret the event log and invoke the appropriate support routines to extract the necessary information for generating user specified output tables. Upon reading the event log, the routine identifies the vessel, the service facility and the nature of the simulation event. Appropriate subroutines are called to process particular sets of data. Figure 8-1 shows a schematic diagram of this program flow. Upon completion of data processing, the event log processor routine resumes control to read the next record on the event log and repeat the cycle. At user specified intervals and at the end of the event log data, printout routines are invoked to generate the requisite output tables.

PROSIM does not gather statistics during the warm-up period, the length of which is user specified, although normal data processing operations are carried out. That is, during the warm-up, simulation events as described by the event log are noted and recorded but statistics are not tabulated.

The ports require a different warm-up period from that of the other fixed facilities in PROSIM because they undergo a different transient state. At the start of the simulation, ports are initialized (perhaps even saturated) with commodity arrivals and vessel introductions and a finite amount of time may be necessary to come down to a "normal" level of traffic[1]. Locks

[1] It is also likely that ports start out with "less than normal" traffic. A separate warm-up time for ports is equally useful in either case, however, the user must be cautious in interpreting the output if two different warm-up periods are indeed specified. In such a case, for example, tonnage flows into ports may not be indicative of the tonnage traffic through other facilities.

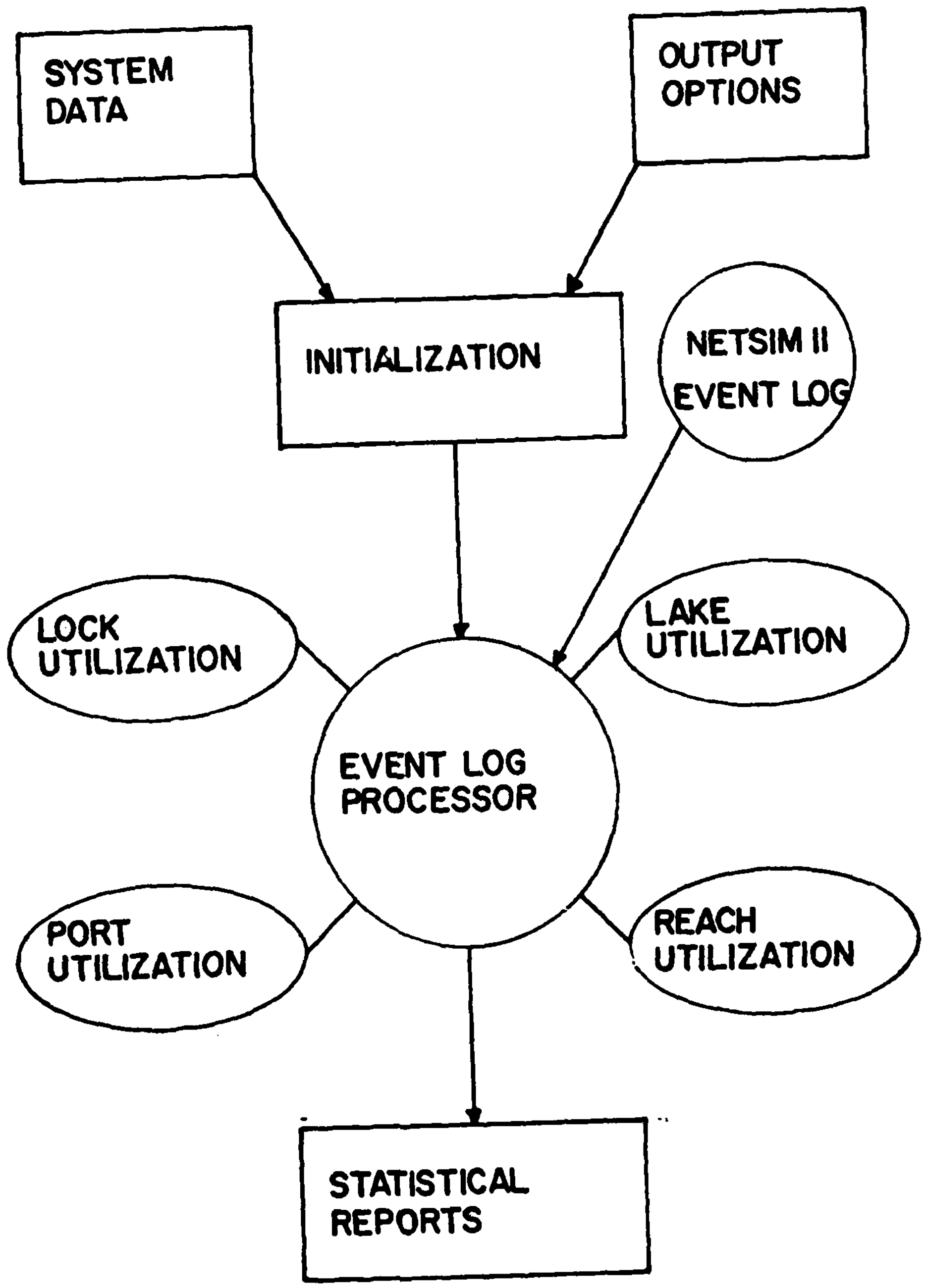


Figure 8-1. PROSIM Program Flow

and reaches, on the other hand, start out in an empty condition (i.e., without traffic) and a warm-up period is necessary for sufficient congestion to build up so that atypical observations are not recorded.[2]

[1]This discussion assumes that the user is interested in the steady-state, rather than the transient, behavior of the waterway system.

CHAPTER 9. OUTPUT

A. INTRODUCTION

The purpose of this chapter is to describe in detail the form of and the calculations made for the PROSIM program output. The output consists of 15 different tables, each of which will be described individually.

PROSIM provides statistical output in three forms. These three forms are: (1) generation of all output tables at the end of the run; (2) generation of all or selected output tables at user specified intervals during the run; and (3) punching selected statistics for further tests of statistical inference at user specified intervals. PROSIM also prefaces these output forms with a description of the waterway system being anaylzed and other items which may aid the user in interpreting the values presented in output tables.

PROSIM provides performance summaries for each category of system facilities. The exact breakdown of the output form is as follows:

Locks - Tables 1 through 7

Ports - Tables 8 through 12

Reaches - Table 13

Lakes - Table 14

NETSIM II's representation of the Welland Canal - Table 15.

Data in these tables may either be accumulated output or calculated output. Accumulated output is simply that which is tabulated as each occurence takes place within the simulation. For example, total delay is simply the accumulated value for delays experienced by all vessels. Calculated output is that which results through some combination of

accumulated data within the program itself. For instance, lock utilization is a statistic which is found by taking total lock processing time (an accumulated value) as a percent of total available time for processing (an input value--usually the simulation length).

In the intermediate output form, PROSIM can produce selected output displays if desired, rather than all fifteen output tables. This selection capability allows generation of less interval output, hence speeding up the program by reducing expensive computer operating time. An instance where all output might not be desired is the situation in which emphasis was placed on only a specific set of variables (e.g., locking operations only) as opposed to the complete simulation results. It should be noted that the final output form always produces a complete set of output tables, regardless of which tables (if any) have been suppressed in the intermediate output form. In any case, the user can, through intermediate output, increase the sample size for his analysis without conducting many separate entire simulations.

The use of intermediate output, however, involves an implicit assumption about the independence of the data. That is, proper application of many statistical methods requires that the data used in the analysis be independent. Observations on a random variable generated at successive points in time in a simulation experiment, however, are generally autocorrelated; treating them as independent underestimates the variance of the corresponding sample mean. This problem can be avoided by taking observations at widely spaced intervals, at the expense of a considerable loss of statistical power or by data transformation which unfortunately is inappropriate in many situations. An alternative approach involves the use of spectral analysis to measure the degree of autocorrelation and take it into account in subsequent tests of inference. This approach has been

documented elsewhere [13]; no description is given here. The use of this approach requires periodic observations on random variables of interest (for example, delays). Therefore, the third output form in PROSIM provides punched data on selected variables to be used as input into subsequent tests of spectral analysis and statistical inference.

In summary, the primary output of PROSIM is the performance summary for each category of waterway facilities represented in the simulation.

B. TABLE 1

Table 1 presents summary statistics on a directional basis for vessels processed at each lock (see Figure 9-1). The format for this table consists of the statistic name in the left-hand column and the name of each lock at the top of the column.

The first three figures are "total tonnage" statistics given by type of cargo. Overseas cargo is all cargo transported by saltwater vessels, dry bulk cargo is that transported by dry bulk vessels and liquid bulk cargo is cargo transported by tankers. The total tonnage data are accumulated statistics developed by adding the total tonnage of the vessel just processed to all previously processed tonnage. As such, these statistics do not include the tonnage data for vessels awaiting service; they include data for only those vessels which were completely serviced at a lock.

The fourth statistic is the "utilization rate" statistic given in percent. This is a calculated statistic found by

$$\frac{\sum_{d} \sum_{t} TT_{dt} - DT_{dt}}{(C - W)} \quad x\ 100$$

TABLE 1 PERFORMANCE DETAILS FOR LOCKS

--"FOR ALL VESSELS"--	ATLANTIC	OTHERSOO	POE	IROQUOIS	EISENHOW	SNELL	UP.BEAUH	LW.BEAUH
TOTAL OVERSEAS CARGO -UP	.	.	.	.	.	.	.	.
DOWN	.	.	.	.	.	.	.	.
TOTAL DRY BULK CARGO - UP	.	.	.	.	.	.	.	.
DOWN	.	.	.	.	.	.	.	.
TOTAL LIQ BULK CARGO -UP	.	.	.	.	.	.	.	.
DOWN	.	.	.	.	.	.	.	.
UTILIZATION RATE (%)	.	.	.	.	.	.	.	.
CURRENT QUEUE LENGTH -UP	.	.	.	.	.	.	.	.
DOWN	.	.	.	.	.	.	.	.
MAXIMUM QUEUE LENGTH -UP	.	.	.	.	.	.	.	.
DOWN	.	.	.	.	.	.	.	.

TABLE 1 PERFORMANCE DETAILS FOR LOCKS

--"FOR ALL VESSELS"--	STE.CATH
TOTAL OVERSEAS CARGO -UP	.
DOWN	.
TOTAL DRY BULK CARGO -UP	.
DOWN	.
TOTAL LIQ BULK CARGO -UP	.
DOWN	.
UTILIZATION RATE (%)	.
CURRENT QUEUE LENGTH -UP	.
DOWN	.
MAXIMUM QUEUE LENGTH -UP	.
DOWN	.

FIGURE 9-1 TABLE 1 in PROSIM

where

TT_{dt} = Total transit time for vessel of classification type t in direction d

DT_{dt} = Total delay time for vessel of classification type t in direction d

C = Current clock time

W = Specified warm-up period.

The numerator in this calculation, i.e., the difference between transit time and delay time, is the processing time for vessels at a lock.

The final two statistics in Table 1 represent the "current queue length" and the "maximum queue length" at each lock. These are both accumulated during the simulation length. The current queue length is simply the number of vessels awaiting service at the time of the printout. This value includes only those vessels waiting because the lock is committed to another vessel and does not include the vessel being serviced.

The maximum queue length is found by comparing the current queue length with the maximum queue length that has occurred thus far during the simulation period. If the current queue is greater than any previous maximum length, then the maximum queue value is changed to the current queue length. The magnitude of this statistic is of concern, since large values[1] would indicate the possibility of an infinite queuing situation.

C. TABLE 2

Table 2 presents four statistics for vessels of class 1[2] processed at each lock. All four statistics are given on a directional basis (see

[1]The criteria for "large values" must be determined through experiment.

[2]Vessel categories are determined by comparing the vessel attributes with user supplied category parameters.

Figure 9-2) and are described below.

"No. of delayed ships" represents accumulated totals of vessels delayed at each specified lock. "Average delay" is a calculated statistic derived in the following manner[3]:

$$\frac{\sum_{i=1}^{V_d} D_{id}}{V_d}\ .$$

where

D_{id} = Total delay time for vessel i in direction d

V_d = Total number of delayed vessels in direction d.

The "std error for delay" is also a calculated statistic derived by using the standard deviation formula[4].

$$\sqrt{\frac{\sum_{i=1}^{V_d} D_{id}^2 - (\bar{D}_d^2 V_d)}{V_d - 1}}$$

where

D_{id} = Delay time for vessel i in direction d

$\bar{D}_d$ = Average delay for vessels delayed in direction d

V_d = Total number of delayed vessels in direction d.

---

[3]This formula will be referenced by "Avg(X_i)" in future text, where X_i is an individual value for statistic X.

[4]This formula will be referenced herein by "S.D($\bar{X}$, X_i)" where $\bar{X}$ is the average value for statistic X, and X_i is the corresponding individual value.

TABLE 2 PERFORMANCE DETAILS FOR LOCKS

	ATLANTIC	OTHERSOO	POE	IROQUOIS	EISENHOW	SNELL	UP.BEAUH	LW.BEAUH
"VESSELS OF LENGTH 1-400 FT"								
NO. OF DELAYED SHIPS -UP	.	.	.	.	.	.	.	.
DOWN	.	.	.	.	.	.	.	.
AVERAGE DELAY -UP	.	.	.	.	.	.	.	.
DOWN	.	.	.	.	.	.	.	.
TOTAL DELAY -UP	.	.	.	.	.	.	.	.
DOWN	.	.	.	.	.	.	.	.
STD ERROR FOR DELAY -UP	.	.	.	.	.	.	.	.
DOWN	.	.	.	.	.	.	.	.

TABLE 2 PERFORMANCE DETAILS FOR LOCKS

	STE.CATH
"VESSELS OF LENGTH 1-400 FT"	
NO. OF DELAYED SHIPS -UP	.
DOWN	.
AVERAGE DELAY -UP	.
DOWN	.
TOTAL DELAY -UP	.
DOWN	.
STD ERROR FOR DELAY -UP	.
DOWN	.

FIGURE 9-2 TABLE 2 in PROSIM

The "total delay time" value is accumulated during the simulation. It represents the total amount of delay incurred at a lock by all vessels passing that lock and thus includes delays in both a stationary position at queue as well as at the short entry position outside chamber gates. Delay in this instance is defined as that time spent at a lock awaiting service and does not include the actual lock service (processing) time.

It is important to note that all the values printed in Table 2 pertain to vessels delayed at a lock and not for all vessels passing through the lock. Thus, if the user desires to obtain average delay for all vessels obtaining lock service, the total delay time statistic must be divided by the total number of ships statistic given in Table 3.

D. TABLE 3

Table 3 presents four additional statistics for all vessels of class 1 processed at each lock. All four statistics are given on a directional basis (see Figure 9-3) and are described below.

"No. of total ships" is the accumulated total of all vessels of class 1 category passing through each lock. This includes both delayed vessels and zero-delayed vessels. "Average transit time" is a calculated statistic computed as the

$$\text{Avg } (TT_{id})$$

where TT_{id} is the transit time for vessel i traveling in direction d. Transit time here is defined as the sum of any delay experienced by a vessel and its lock processing time. Therefore, if the lock service time is a constant, it could be subtracted from the average transit time to derive the average delay time for all vessels of class 1.

TABLE 3 PERFORMANCE DETAILS FOR LOCKS

	ATLANTIC	OTHERSOO	POE	IROQUOIS	EISENHOW	SNELL	UP.BEAUH	LW.BEAUH
"VESSELS OF LENGTH 1-400 FT"								
NO. OF TOTAL SHIPS -UP	.	.	.	.	.	.	.	.
DOWN	.	.	.	.	.	.	.	.
AVERAGE TRANSIT TIME -UP	.	.	.	.	.	.	.	.
DOWN	.	.	.	.	.	.	.	.
TOTAL TRANSIT TIME -UP	.	.	.	.	.	.	.	.
DOWN	.	.	.	.	.	.	.	.
STD ERROR FOR TRANSIT -UP	.	.	.	.	.	.	.	.
DOWN	.	.	.	.	.	.	.	.

TABLE 3 PERFORMANCE DETAILS FOR LOCKS

	STE.CATH
"VESSELS OF LENGTH 1-400 FT"	
NO. OF TOTAL SHIPS -UP	.
DOWN	.
AVERAGE TRANSIT TIME -UP	.
DOWN	.
TOTAL TRANSIT TIME -UP	.
DOWN	.
STD ERROR FOR TRANSIT -UP	.
DOWN	.

FIGURE 9-3 TABLE 3 in PROSIM

The "total transit time" is an accumulated statistic found by summing the time spent by each vessel waiting and processing at a lock. The "std error for transit" is the standard deviation of the transit time for each vessel and is computed as the

$$S.D\ (\bar{T}_d\ ,\ T_{id})$$

where $\bar{T}_d$ is the average transit time and T_{id} is the transit time for vessel i in direction d.

E. TABLE 4

Table 4 is very similar to Table 2, however, the statistics given are for Class 2 vessels. All statistics are computed in exactly the same manner as for Table 2.

F. TABLE 5

Table 5 is similar to Table 3, however, the transit information given pertains to vessels of Class 2. All statistics are computed exactly as previously described.

G. TABLE 6

Table 6 is similar to Tables 2 and 4, however, the delay statistics given are for Class 3 vessels.

H. TABLE 7

Table 7 is similar to Tables 3 and 5, however, the transit data given pertain to vessels of Class 3.

I. TABLE 8

Table 8 supplies tonnage statistics for all vessels processed at each port (see Figure 9-4). The format for this table consists of the statistic name in the left-hand column and the name of each port at the top of the column.

The tonnage statistics include "total tonnage into port" and the "total tons out of port". Each total is decomposed into the following cargo types:

(1) "overseas" - all cargo carried by saltwater vessels

(2) "liquid bulk" - all cargo carried by tankers

(3) "dry bulk (excl.grain)" - all dry bulk excluding grain

(4) "grain" - all grain shipments.

These statistics are accumulated values giving the total tonnage by cargo type carried by all vessels into and out of each port. The statistics do not include any cargo which may be in the process of being loaded onto a vessel, nor do they include the commodity inventory at port (i.e., cargo not committed to any vessel).

J. TABLE 9

Table 9 presents the total number of vessels entering and exiting each port (see Figure 9-5). This table is similar to Table 8 in that the format is similar and each statistical total is broken down into the same cargo types. Thus, "overseas" is interpreted as the number of saltwater vessels and "grain" means the number of dry bulk vessels transporting grain.

TABLE 8 PERFORMANCE DETAILS FOR PORTS

	TORONTO	DULUTH	MARQUETT	ESCANABA	MILWAUKE	CHICAGO	GARY	MUSKEGON
TOTAL TONNAGE INTO PORT	.	.	.	.	.	.	.	.
OVERSEAS	.	.	.	.	.	.	.	.
LIQUID BULK	.	.	.	.	.	.	.	.
DRY BULK (EXCL. GRAIN)	.	.	.	.	.	.	.	.
GRAIN	.	.	.	.	.	.	.	.
TOTAL TONS OUT OF PORT	.	.	.	.	.	.	.	.
OVERSEAS	.	.	.	.	.	.	.	.
LIQUID BULK	.	.	.	.	.	.	.	.
DRY BULK (EXCL. GRAIN)	.	.	.	.	.	.	.	.
GRAIN	.	.	.	.	.	.	.	.

TABLE 8 PERFORMANCE DETAILS FOR PORTS

	ALPENA	DETROIT	TOLEDO	CLEVELAND	BUFFALO	HAMILTON	INL.WATS	US.COAST
TOTAL TONNAGE INTO PORT	.	.	.	.	.	.	.	.
OVERSEAS	.	.	.	.	.	.	.	.
LIQUID BULK	.	.	.	.	.	.	.	.
DRY BULK (EXCL. GRAIN)	.	.	.	.	.	.	.	.
GRAIN	.	.	.	.	.	.	.	.
TOTAL TONS OUT OF PORT	.	.	.	.	.	.	.	.
OVERSEAS	.	.	.	.	.	.	.	.
LIQUID BULK	.	.	.	.	.	.	.	.
DRY BULK (EXCL. GRAIN)	.	.	.	.	.	.	.	.
GRAIN	.	.	.	.	.	.	.	.

FIGURE 9-4 TABLE 8 in PROSIM

TABLE 9 PERFORMANCE DETAILS FOR PORTS

	TORONTO	DULUTH	MARQUETT	ESCANABA	MILWAUKE	CHICAGO	GARY	MUSKEGON
TOTAL SHIPS INTO PORT	.	.	.	.	.	.	.	.
OVERSEAS	.	.	.	.	.	.	.	.
LIQUID BULK	.	.	.	.	.	.	.	.
DRY BULK (EXCL. GRAIN)	.	.	.	.	.	.	.	.
GRAIN	.	.	.	.	.	.	.	.
TOTAL SHIPS OUT OF PORT	.	.	.	.	.	.	.	.
OVERSEAS	.	.	.	.	.	.	.	.
LIQUID BULK	.	.	.	.	.	.	.	.
DRY BULK (EXCL. GRAIN)	.	.	.	.	.	.	.	.
GRAIN	.	.	.	.	.	.	.	.

TABLE 9 PERFORMANCE DETAILS FOR PORTS

	ALPENA	DETROIT	TOLEDO	CLEVELAND	BUFFALO	HAMILTON	INL.WATS	US.COAST
TOTAL SHIPS INTO PORT	.	.	.	.	.	.	.	.
OVFRSEAS	.	.	.	.	.	.	.	.
LIQUID BULK	.	.	.	.	.	.	.	.
DRY BULK (EXCL. GRAIN)	.	.	.	.	.	.	.	.
GRAIN	.	.	.	.	.	.	.	.
TOTAL SHIPS OUT OF PORT	.	.	.	.	.	.	.	.
OVERSEAS	.	.	.	.	.	.	.	.
LIQUID BULK	.	.	.	.	.	.	.	.
DRY BULK (EXCL. GRAIN)	.	.	.	.	.	.	.	.
GRAIN	.	.	.	.	.	.	.	.

FIGURE 9-5 TABLE 9 in PROSIM

K. TABLE 10

Table 10 presents two statistics, "average turnaround time" and "average delay for berth use," for all vessels processed at each port (see Figure 9-6). These statistics are presented according to the same cargo types defined previously.

Average turnaround time is the average of all times spent by vessels at a port and is computed as the time between a vessel's entry into a port and its subsequent exit from that port. This statistic includes any delays experienced while waiting for suitable cargo or for a berth or due to any random delay factor as well as the actual loading and unloading times.

Average delay for berth use is more specifically the average delay encountered by vessels delayed by the unavailability of a suitable berth for unloading or loading or both. This statistic is computed for delayed vessels only and does not include zero-delayed vessels or vessels encountering types of delays other than the ones mentioned.

L. TABLE 11

Table 11 is produced optionally at the user's specification and supplies the "average queue for berth use" and the "average loading time" (see Figure 9-7). These statistics are presented according to previously defined cargo types.

Average queue for berth use is the average length of a berth queue and consists of the average number of vessels awaiting a free berth for loading or unloading.

TABLE 10 PERFORMANCE DETAILS FOR PORTS

	TORONTO	DULUTH	MARQUETT	ESCANABA	MILWAUKE	CHICAGO	GARY	MUSKEGON
"AVERAGE TURNAROUND TIME"								
OVERSEAS	.	.	.	.	.	.	.	.
LIQUID BULK	.	.	.	.	.	.	.	.
DRY BULK (EXCL. GRAIN)	.	.	.	.	.	.	.	.
GRAIN	.	.	.	.	.	.	.	.
"AVERAGE DELAY FOR BERTH USE"								
OVERSEAS	.	.	.	.	.	.	.	.
LIQUID BULK	.	.	.	.	.	.	.	.
DRY BULK (EXCL. GRAIN)	.	.	.	.	.	.	.	.
GRAIN	.	.	.	.	.	.	.	.

TABLE 10 PERFORMANCE DETAILS FOR PORTS

	ALPENA	DETROIT	TOLEDO	CLEVELAND	BUFFALO	HAMILTON	INL.WATS	US.COAST
"AVERAGE TURNAROUND TIME"								
OVERSEAS	.	.	.	.	.	.	.	.
LIQUID BULK	.	.	.	.	.	.	.	.
DRY BULK (EXCL. GRAIN)	.	.	.	.	.	.	.	.
GRAIN	.	.	.	.	.	.	.	.
"AVERAGE DELAY FOR BERTH USE"								
OVERSEAS	.	.	.	.	.	.	.	.
LIQUID BULK	.	.	.	.	.	.	.	.
DRY BULK (EXCL. GRAIN)	.	.	.	.	.	.	.	.
GRAIN	.	.	.	.	.	.	.	.

[illegible]RE [illegible] BLE [illegible] in [illegible]IM

TABLE 11 PERFORMANCE DETAILS FOR PORTS

	TORONTO	DULUTH	MARQUETT	ESCANABA	MILWAUKE	CHICAGO	GARY	MUSKEGON
"AVERAGE QUEUE FOR BERTH USE"								
OVERSEAS	.	.	.	.	.	.	.	.
LIQUID BULK	.	.	.	.	.	.	.	.
DRY BULK (EXCL. GRAIN)	.	.	.	.	.	.	.	.
GRAIN	.	.	.	.	.	.	.	.
"AVERAGE LOADING TIME"								
OVERSEAS	.	.	.	.	.	.	.	.
LIQUID BULK	.	.	.	.	.	.	.	.
DRY BULK (EXCL. GRAIN)	.	.	.	.	.	.	.	.
GRAIN	.	.	.	.	.	.	.	.

TABLE 11 PERFORMANCE DETAILS FOR PORTS

	ALPENA	DETROIT	TOLEDO	CLEVELAND	BUFFALO	HAMILTON	INL.WATS	US.COAST
"AVERAGE QUEUE FOR BERTH USE"								
OVERSEAS	.	.	.	.	.	.	.	.
LIQUID BULK	.	.	.	.	.	.	.	.
DRY BULK (EXCL. GRAIN)	.	.	.	.	.	.	.	.
GRAIN	.	.	.	.	.	.	.	.
"AVERAGE LOADING TIME"								
OVERSEAS	.	.	.	.	.	.	.	.
LIQUID BULK	.	.	.	.	.	.	.	.
DRY BULK (EXCL. GRAIN)	.	.	.	.	.	.	.	.
GRAIN	.	.	.	.	.	.	.	.

FIGURE 9-7 TABLE 11 in PROSIM

Average loading time is defined as the average of all times spent by vessels in a berth for the loading process. This statistic is supplied for calibration purposes so that the user may verify that the value given indeed represent the input data for ports.

M. TABLE 12

Table 12 is also generated at the user's option and consists of two statistics. "Average unloading time" is the average time spent by vessels in a berth for unloading, broken down by the four cargo types. The "wait for cargo summary" statistic is comprised of two elements. "No. of ships waiting" is the total number of vessels, regardless of type, waiting in cargo queues for a suitable cargo. "Weighted queue length" is a time-dependent variable which weights a collection of queue size observations by the length of time they have had their values. This variable is calculated as follows:

$$\frac{\sum_{i=1}^{n} Q_i (T_n - T_c)}{C}$$

where

- n = Number of times queue size changes, i.e., number of times vessels enter and exit cargo queue
- Q_i = Sample value of cargo queue size before it changes to to a new value
- T_c = Simulation time at which cargo queue was set to its current value
- T_n = Simulation time at which cargo queue changes to a new value
- C = Simulation time at printout.

This output is a better measure of the state of the cargo queue than a simple time independent average and is given in Table 12 for calibration purposes. Inordinately large values for this statistic may indicate abnormal imbalance between transportation supply and demand. Figure 9-8 provides an example output for Table 12.

N. TABLE 13

Table 13 gives performance details for reaches (see Figure 9-9). Included are the following statistics:

"No. of total ships"

"Average transit time"

"Total transit time"

"Std error for transit."

These statistics are given for each class of vessels, and are computed in the previously described manner. This output is generated when vessels complete their transit through reaches; the output does not include vessels in the process of passage at the time of printout.

O. TABLE 14

Table 14 gives the "total no. of ships" and the "total transit time" measures for each lake in the system (see Figure 9-10), where these statistics are defined as previously. Additional output such as average transit times are not computed since they vary between different node points on the lake.

TABLE 12 PERFORMANCE DETAILS FOR PORTS

	TORONTO	DULUTH	MARQUETT	ESCANABA	MILWAUKE	CHICAGO	GARY	MUSKEGON
"AVERAGE UNLOADING TIME"								
OVERSEAS	.	.	.	.	.	.	.	.
LIQUID BULK	.	.	.	.	.	.	.	.
DRY BULK (EXCL. GRAIN)	.	.	.	.	.	.	.	.
GRAIN	.	.	.	.	.	.	.	.
"WAIT FOR CARGO SUMMARY"								
NO. OF SHIPS WAITING	.	.	.	.	.	.	.	.
WEIGHTED QUEUE LENGTH	.	.	.	.	.	.	.	.

TABLE 12 PERFORMANCE DETAILS FOR PORTS

	ALPENA	DETROIT	TOLEDO	CLEVELAND	BUFFALO	HAMILTON	INL.WATS	US.COAST
"AVERAGE UNLOADING TIME"								
OVERSEAS	.	.	.	.	.	.	.	.
LIQUID BULK	.	.	.	.	.	.	.	.
DRY BULK (EXCL. GRAIN)	.	.	.	.	.	.	.	.
GRAIN	.	.	.	.	.	.	.	.
"WAIT FOR CARGO SUMMARY"								
NO. OF SHIPS WAITING	.	.	.	.	.	.	.	.
WEIGHTED QUEUE LENGTH	.	.	.	.	.	.	.	.

FIGURE 9-8 TABLE 12 in PROSIM

TABLE 13 PERFORMANCE DETAILS FOR REACHES

	ST.LAMBI	SOO.R.1	SOO.R.2	SOO.R.3	SOO.R.4	SOO.R.5	ST.CLAIR	SLS.R.1
"VESSELS OF LENGTH 1-400 FT"								
NO. OF TOTAL SHIPS	.	.	.	.	.	.	.	.
AVERAGE TRANSIT TIME	.	.	.	.	.	.	.	.
TOTAL TRANSIT TIME	.	.	.	.	.	.	.	.
STD ERROR FOR TRANSIT	.	.	.	.	.	.	.	.
"VESSELS OF LENGTH 400-740 FT"								
NO. OF TOTAL SHIPS	.	.	.	.	.	.	.	.
AVERAGE TRANSIT TIME	.	.	.	.	.	.	.	.
TOTAL TRANSIT TIME	.	.	.	.	.	.	.	.
STD ERROR FOR TRANSIT	.	.	.	.	.	.	.	.
"VESSELS OF LENGTH 740- FT"								
NO. OF TOTAL SHIPS	.	.	.	.	.	.	.	.
AVERAGE TRANSIT TIME	.	.	.	.	.	.	.	.
TOTAL TRANSIT TIME	.	.	.	.	.	.	.	.
STD ERROR FOR TRANSIT	.	.	.	.	.	.	.	.

FIGURE 9-9 TABLE 13 in PROSIM

TABLE 14 PERFORMANCE DETAILS FOR LAKES

	ONTARIO	SUPERIOR	MICHIGAN	HURON	ERIE
"VESSELS OF LENGTH 1-400 FT"					
NO. OF TOTAL SHIPS	.	.	.	.	.
TOTAL TRANSIT TIME	.	.	.	.	.
"VESSELS OF LENGTH 400-740 FT"					
NO. OF TOTAL SHIPS	.	.	.	.	.
TOTAL TRANSIT TIME	.	.	.	.	.
"VESSELS OF LENGTH 740- FT"					
NO. OF TOTAL SHIPS	.	.	.	.	.
TOTAL TRANSIT TIME	.	.	.	.	.

FIGURE 9-10 TABLE 14 in PROSIM

P. TABLE 15

Table 15 provides the summary statistics for the Welland Canal as represented in NETSIM II. The format of the table and the statistics generated are shown in Figure 9-11.

The first statistic is the "total number of ships" entering the Canal, an accumulated statistic. The second statistic is the "total tonnage" carried by vessels entering the Canal, also an accumulated statistic. Both of these outputs are broken down according to whether they belong to overseas, dry bulk or liquid bulk categories. The third output is the "average transit time", computed as the average time spent in the Canal. The final output is the "average waiting time", a calculated delay statistic.

TABLE 15 PERFORMANCE DETAILS FOR THE WELLAND CANAL

TOTAL NUMBER OF SHIPS

OVERSEAS

LIQ BULK

DRY BULK

TOTAL TONNAGE

OVERSEAS

LIQ BULK

DRY BULK

AVERAGE TRANSIT TIME

AVERAGE WAITING TIME

FIGURE 9-11 TABLE 15 in PROSIM

APPENDIX C

PROSIM USER MANUAL

A. INTRODUCTION

This manual provides the information needed to prepare the input data for the PROSIM portion of the simulation package. It is assumed that the reader is thoroughly familiar with Part I of this publication dealing with the input, output and operations of NETSIM II. Since the numbering conventions used to input data for PROSIM must agree completely with those used in NETSIM II, such familiarity is indispensable.

B. INPUT DATA FORMATS

A PROSIM data deck consists of the two classes of data described in Chapter 7. Some of these data are in fixed format and others can be input in free form. For the latter, there are two governing restrictions. First, each datum must be separated from its adjoining data by at least one blank. Second, a datum must not be continued from one card to the next. Data may be punched as either real or integer except as otherwise specified. The important thing to remember about the free-form concept is that the program reads free-form input as a continuous stream of values. Successive numerical values are read and assigned to corresponding variables in the read command. The location of a particular datum on a card is not considered, (except as noted--some data must start in column 1 where indicated) as long as it is properly positioned relative to other data. Unless otherwise stated, all data below can be input in free form.

Card Format Specifications

Item Number	Contents
A1	N.PORT Number of ports.
A2	N.LOCK Number of locks.
A3	N.REACH Number of reaches.
A4	N.LAKE Number of lakes.
A5	SWITCH.FOR.WELLAND This code is 1 if NETSIM II's representation of the Welland Canal is to be used, 0 otherwise.
A6	N.VESSEL Number of vessels--this number need not be exact but it must be equal to or greater than the number of vessels used in NETSIM II. A lower number will result in program termination with an addressing error.
A7	SEASON.LENGTH This is the total simulation time including any warm-up time needed to achieve steady state.
A8	WARMUP.TIME This is the warm-up period for locks, reaches and lakes.
A9	PRT.WARMUP.TIME Warm-up period for ports.
A10	INTER.MEDIATE.PRINTOUT Simulation interval between intermediate statistical reports.
A11	HI.PORT Identification number of the highest numbered port.
A12	HI.LOCK Identification number of the highest numbered lock.
A13	HI.REACH Identification number of the highest numbered reach.

Item Number	Contents
A14	HI.LAKE Identification number of the highest numbered lake.
A15	1.CLASS Vessel length upper bound for Class 1, in tens of feet.
A16	2.CLASS Vessel length upper bound for Class 2, in tens of feet.
A17	GRN.INDEX Code representing grain cargo.
A18	P.DEVICE Output unit for punching selected statistics.
A19	INPUT.DEVICE Input unit for reading the NETSIM II event log.
A20	O.1 This code is 1 if the lock tables 1 through 7 are to be printed during the intermediate printouts, 0 otherwise.
A21	O.2 This code is 1 if the port tables 8 through 10 are to be printed during the intermediate printouts, 0 otherwise.
A22	O.3 This code is 1 if Table 13 (reach) is to be printed during the intermediate printouts, 0 otherwise.
A23	O.4 This code is 1 if Table 14 (lake) is to be printed during the intermediate printouts, 0 otherwise.
A24	CAL.ID This code is 1 if the port tables 11 and 12 are to be printed (both for intermediate printouts and final printout), 0 otherwise.
A25	RUN.ID Identification number for the simulation run.

Item Number	Contents
A26	Identification Numbers PROSIM requires identification numbers for each fixed facility in the system and the numbers given must agree exactly with those in NETSIM II (see the section on "Numbering Convention in NETSIM II" in the NETSIM II User Manual, pp. 58-60 of this publication). The order in which the identification numbers are given is as follows (free form): Starting in cc 1 of a new card, identification number for each port identification number and upstream node for each lock identification number for each reach identification number for each lake. That is, the identification numbers for ports must precede those for locks, etc.
A27	Alphameric Names PROSIM requires an alphameric name for each fixed facility in the system (ports, locks, reaches and lakes). A name can consist of up to eight characters. The names must be given in the same sequence as the identification numbers (item A26). Each name is in columns 1-8 of a new card (one name per card). Within each category of facilities, the input names must be ordered by the sequence of their identification number. This is illustrated below.

Ports

Card 1	cc 1-8	Name of the first port (port with identification number = 1)
Card 2	cc 1-8	Name of the second port
	.	
	.	
	.	
Card 10	cc 1-8	Name of the tenth port
	.	
	.	
	.	

Locks

	cc 1-8	Name of the first lock
	.	
	.	
	.	

Reaches

cc 1-8 Name of the first reach

.
.
.

Lakes

cc 1-8 Name of the first lake

.
.
.

These input data must be supplied in the exact order and manner as shown above.

B1

NETSIM II EVENT LOG

The event log is a collection of data records generated as output by NETSIM II and input to PROSIM through an auxiliary device such as magnetic tape, card file, etc. Each record in the event log has eleven elements with the following format (4 I 4 , I 3 , I 1 , I 2 , I 1 , 2 I 4 , D(7,0)).

Item	Column	Format	Description
1	1-4	I 4	Vessel identification number
2	5-8	I 4	Vessel length in tens of feet
3	9-12	I 4	Vessel's current node number
4	13-16	I 4	Vessel's next node number
5	17-19	I 3	Vessel's cargo tonnage in hundreds of tons
6	20	I 1	Commodity type
7	21-22	I 2	Code for dedicated cargo
8	23	I 1	Vessel classification code
9	24-27	I 4	Facility identification number
10	28-31	I 4	Event code
11	32-38	D(7,0)	Simulation time

C. ERROR MESSAGES

This section describes all error messages generated by PROSIM. The possible reasons for the generation of each massage and recommended user action are also described. PROSIM's error messages are most often the result of some inconsistency between its input data and that for NETSIM II. To avoid costly reruns, the user is urged to inspect his data carefully in order to insure that this is not the case.

-------PROSIM ERROR MESSAGE 1101-------

UNIDENTIFIABLE FACILITY ID AAAA IN SIMULATION EVENT.LOG WITH EVENT.CODE BBBB AT SIMULATION TIME CCCCCC

This error is discovered by the event log processor routine and may be attributed to the following:

(1) incorrect identification numbers (item A26) due to keypunch mistakes, omission of a number, etc., or inconsistency with the identification numbers input to NETSIM II;

(2) access to the wrong NETSIM II event log.

-------PROSIM ERROR MESSAGE 1201-------

INCORRECT CLASSIFICATION NUMBER AAAA IN SIMULATION EVENT.LOG WITH VESSEL ID DDDD EVENT.CODE BBBB AT SIMULATION TIME CCCCCC

The vessel classification codes in the NETSIM II-PROSIM simulation package are as follows:

1 = saltwater vessels

2 = liquid bulk carriers

3 = dry bulk carriers.

Any deviation from this numbering scheme will result in the above error and program termination. There are three corrective actions listed in order of increasing programming difficulty:

(1) rerun NETSIM II simulation with correct vessel classification codes;

(2) modify the event log to reflect the correct codes;

(3) modify PROSIM to accept user's numbering system.

------PROSIM ERROR MESSAGE 1301------

INCORRECT CLASSIFICATION NUMBER AAAA FOR EVENT.CODE 9180 IN SIMULATION EVENT.LOG WITH VESSEL BBBB ---PORT CCCC AT SIMULATION TIME DDDDDDD

Vessel classification code should be 1 for event code 9180 in NETSIM II. The user is referred to the corrective action listed for error 1201.

------PROSIM ERROR MESSAGE 1302------

ERROR FOR EVENT.CODE 9190 IN SIMULATION PROGRAM VESSEL AAAA ---PORT BBBB ---TIME CCCCCCC

This error indicates an identification number of 0 for a destination port in the commodity arrival list input for NETSIM II, hence, the error would normally be discovered during simulation. If this error does reach PROSIM, this is an indication of a basic abnormality in the numbering scheme for NETSIM II. The user should reevaluate NETSIM II input data and submit a revised run.

------PROSIM ERROR MESSAGE 5101------

INCORRECT CLASSIFICATION NUMBER AAAA IN SIMULATION EVENT.LOG WITH VESSEL BBBB ---EVENT.CODE CCCC AT TIME DDDDDDD

This error is encountered by the Welland passage routine. Corrective action is listed under error 1201.

PART III

SUPPORT PROGRAMS FOR THE SIMULATION PACKAGE--

DESCRIPTIONS AND USER MANUALS

CHAPTER 10. VESSEL GENERATION PROGRAM

A. PROGRAM DESCRIPTION

This program produces CREAT.VESSEL external event notices for direct input into NETSIM II. The user must supply, as data, a "pool" of representative vessels. The program then generates vessel arrivals into the system (CREAT.VESSEL cards) at specified times by making random selections from this pool according to user-specified probability distributions. The ports into which the vessels are introduced are then chosen independently according to another set of distributions.

More specifically, the user must supply the following:

1. Pool of representative vessels. This is really three separate pools, one for each of the three vessel classifications (dry bulk, liquid bulk and saltwater). For each vessel in the pool must be supplied data for all of the attributes that appear in the CREAT.VESSEL card. Also, for each vessel the user must give the frequency with which it will be selected relative to other vessels in the pool with the same vessel classification. These frequencies are given as decimal fractions which must add to unity within each classification.

2. Port data. For each port-vessel classification combination, the user must specify the probability that a vessel of the given class will be introduced into the system at the given port. Again, the probabilities within each classification must sum to unity.

3. Vessel creation time specification. This is simply a series of cards, each of which gives

   (a) the number of each class of vessel to be created

   (b) when they are to be created.

   A new card is required for each different time (simulation time), but there is no limit to the number of vessels to be created (CREAT.VESSEL cards to be generated) from a single card. (All of the CREAT.VESSEL cards generated from a single input data card will have the same value in the TIME.V field).

Production of CREAT.VESSEL cards by the program is rather straightforward, proceeding as follows:

1. A vessel creation time specification card (see 3 above) is read in. This specifies a time and the number of vessels to be generated in each class.

2. Beginning with vessel class 1, a vessel (set of vessel attributes) is selected from the pool of vessels of that class according to the given probability distribution.

3. A port is selected according to the port selection probability distribution for the given vessel class.

4. A CREAT.VESSEL record is written (to unit 1) with the given time and the selected port and vessel attributes.

Steps 2 through 4 are repeated until the specified number of vessels of each class have been created. Then the next vessel creation time specification card is read and the process is continued. The run terminates when no more cards remain to be read. Generated vessels are numbered sequentially, beginning with one. These numbers are placed in columns 66 through 71 of the CREAT.VESSEL records by the program.

Immediately following is a user manual which describes the data requirements and outputs in detail.

B. USER MANUAL

1. Input Data Stream

In the following data descriptions all numbers are to be punched right justified in the indicated fields with no decimal points. The user should keep in mind that both trailing and leading blanks are interpreted as zeroes. Note that a number of vessel attributes are required in card type 2. For convenience, these are in the same card columns in which they appear in the CREAT.VESSEL cards. For further description of the attributes refer to Chapter 2 and pages 83-85 in Appendix A.

Card Type	Columns	Description
1	1-10	Number of representative vessels in the classification 1 pool, NVES1.
2	1-10	1000 times the probability of selecting this vessel.
	24-27	OVERALL.LENGTH(VESSEL) in tens of feet.
	28-33	HORSEPOWER(VESSEL) in hundreds of horsepower.
	34-39	CAPACITY(VESSEL) in hundreds of tons.
	40-44	UNLOADING.RATE(VESSEL) (for self-unloading vessels only).
	45-47	DRAFT(VESSEL) in feet.
	48-49	CLASSIF(VESSEL)
	50-53	MT.BACK(VESSEL)
	54-59	CARGO.TONNAGE(VESSEL) in hundreds of tons.
	60-61	CARG.TYP(VESSEL)
	62-65	ORIGIN(VESSEL)
		The number of type 2 cards is NVES1; that is, one for each vessel in the class 1 pool.
3	1-10	Number of representative vessels in the classification 2 pool, NVES2.
4		Same format as card type 2. There are NVES2 of these.
5	1-10	Number of representative vessels in the classification 3 pool, NVES3.
6		Same format as card type 2. There are NVES3 of these.
7	1-10	Number of ports, NPORT.
8	1-10	Port number.

Card Type	Columns	Description
	11-20	1000 times the probability of this port's being selected as the entry point for a class 1 vessel.
	21-30	1000 times the probability of this port's being selected as the entry point for a class 2 vessel.
	31-40	1000 times the probability of this port's being selected as the entry point for a class 3 vessel.
		There is one type 8 card for each port.
9	1-10	Time that vessels are to be created. TIME.V
	11-20	Number of class 1 vessels to be created at time TIME.V.
	21-30	Number of class 2 vessels to be created at time TIME.V.
	31-40	Number of class 3 vessels to be created at time TIME.V.
		There is one type 9 card for each time that one or more vessels are to be created.

2. Outputs

The primary output is cards that serve as CREAT.VESSEL external event notices in NETSIM II. The format is as follows:

Columns	Description
1-12	Characters "CREAT.VESSEL"
13-20	Simulation time that the event is to occur (TIME.V). The number is in an F format, so that the character in column 20 is a decimal point.
21-23	Number of the port into which the vessel is to be introduced.

Columns	Description
24-71	Attribute data for the vessel. The format is identical to that for a type 2 input card, described above.
80	"*" Signals end of data for an external event notice.

In addition to producing CREAT.VESSEL cards, the program prints out the number of each class of vessel which will be created at each port.

AD-A111 840 PENNSYLVANIA TRANSPORTATION AND TRAFFIC SAFETY CENTER--ETC F/6 13/2
GREAT LAKES-ST. LAWRENCE SEAWAY SIMULATION STUDIES. VOLUME 4. N--ETC(U)
DEC 73 J L CARROLL, S RAO, H G WILSON DACW23-72-C-0066

UNCLASSIFIED TTSC-7319 NL

3 3

END
DATE
FILMED
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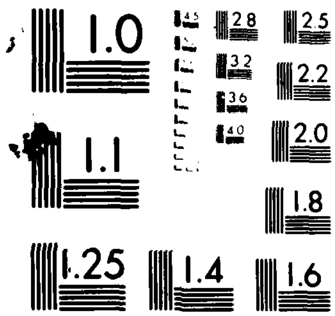

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

CHAPTER 11. COMMODITY ARRIVAL GENERATION PROGRAM

A. PROGRAM DESCRIPTION

This program produces COM.ARRIVAL external event notices for direct input into NETSIM II. These provide for the simulation of overland arrivals of commodities into ports in the system. The program allows only for a uniform (periodic) deterministic flow of commodities into each port. It is intended merely as an expedient for data preparation in that it relieves the user of the task of physically reproducing the data for each inter-arrival period. The commodities which are introduced into the ports in this manner are, of course, those that will in the future become cargoes for the vessels in the system. For each module of cargo must be specified

(1) the port at which it is arriving
(2) the commodity type
(3) its destination within the system
(4) the quantity.

Following is a user manual which describes the program's inputs and outputs in detail.

B. USER MANUAL

1. Input Data Stream

All values must be right-justified in the indicated fields. The user should keep in mind that all leading and trailing blanks are interpreted as zeroes.

Card Type	Columns	Description
1	1-10	The number of type 2 cards to follow.
2	1-10	Port number into which the commodity is to be introduced.

Card Type	Columns	Description
	11-20	Commodity type.
	21-30	Destination (port number).
	31-40	Commodity quantity in hundreds of tons.
		There will be one type 2 card for each port-commodity-destination combination. The type 2 cards must be sequenced in increasing order by commodity type within port number. The last type 2 card must have zeroes in all four fields to signal end of data (to the NETSIM II program).
3	1-10	Time (simulation time) at which the commodity arrivals described in the type 2 cards are to occur.
		There will be one type 3 card for each time at which commodities are to arrive in port.

2. Outputs

The only program output consists of the COM.ARRIVAL event notices.

Each event notice is made up of several records as follows:

Card Type	Columns	Description
1	1-11	Characters "COM.ARRIVAL".
	12-20	Time that the external event is to occur (TIME.V). That is, the simulation time at which the commodities are to arrive in port. The format type is "F", so that column 20 always contains a decimal point.
2		The format and data are identical to those for type 2 cards in the input stream. That is, the type 2 input cards are reproduced without change.
3	1	"*" signals end of data in the external event notice.

This sequence of output records is repeated for each type 3 input card. Note that the output records are referred to as "cards", but they can just as easily be 80 character records on disk or tape.

CHAPTER 12. ITINERARY GENERATION PROGRAM

A. PROGRAM DESCRIPTION

This is a FORTRAN program which generates itineraries for saltwater vessels in NETSIM II. The itineraries are written in a format which is directly readable by the NETSIM II program (in the routine ENT.PORT). Each itinerary consists of

(1) The number of stops (ports)

(2) For each stop

  (a) the port number

  (b) the fraction of the vessel's tonnage to unload at the port

  (c) the fraction of the tonnage (capacity) to load at the port.

It is assumed that the saltwater vessels are entering the system via the St. Lawrence River. Figure 12-1 shows schematically the shape of the network for which this program is designed. It would not be applicable to a system with any other configuration. Figure 12-2 illustrates that the Great Lakes-St. Lawrence Waterway System fits the scheme. The primary aspects of the scheme are:

(1) There is only a single point at which a vessel may enter or leave the system.

(2) At the "other end" of the system from the entry/exit point is a fork creating two distinct branches.

(3) At some point between the fork and the entry/exit point, the system is conceptually divided into upper and lower subsystems.

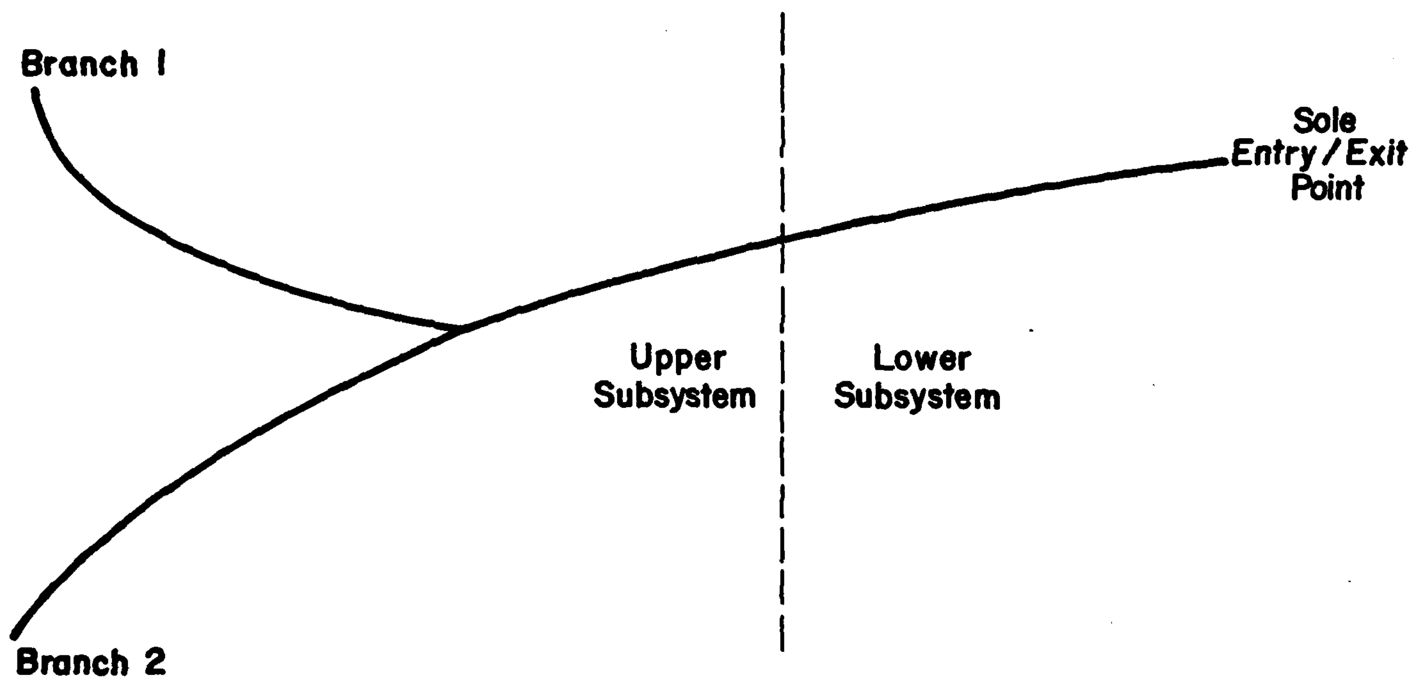

Figure 12-1. Schematic Representation of the Network Used in the Itinerary Generation Program

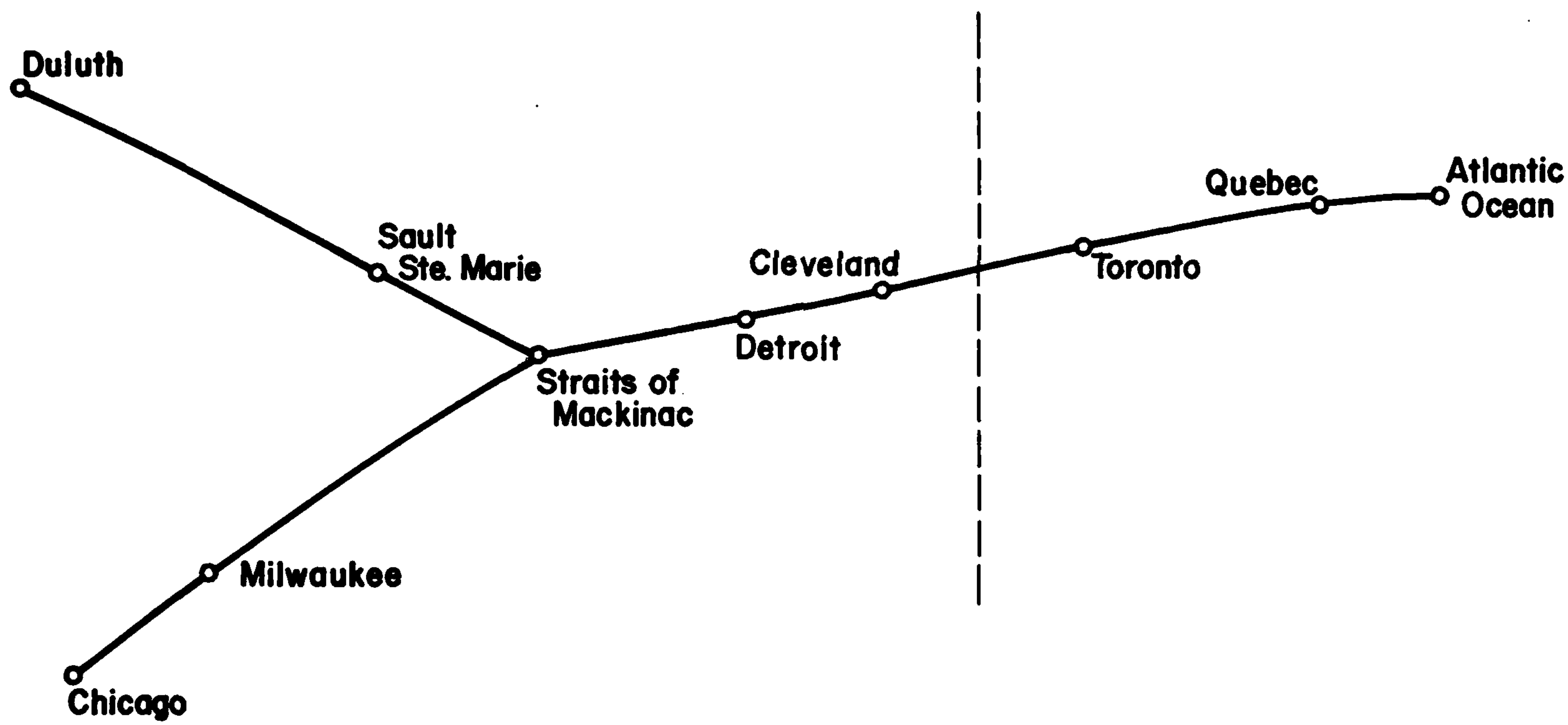

Figure 12-2. Schematic Representation of the Great Lakes-St. Lawrence Seaway System

For the GL-SLS, the dividing point is the Welland Canal. The program generates itineraries such that Branch 1 and Branch 2 are never both entered on the same itinerary.

There are a number of empirical statistics that can be used to describe actual itineraries of saltwater vessels. Not all such parameters can be specified independently for purposes of random itinerary generation, however. Hence, decisions had to be made as to which parameters would be input by the user and which would subsequently be calculated automatically by the program. The following example illustrates this point.

Adopt the following notation:

$E(X)$ expected value of a random variable, X

Let P = probability that a vessel goes through Welland

T_I = total inbound tonnage (into the system on saltwater vessels)

T_O = total outbound tonnage

T_{IA} = total inbound tonnage terminating above Welland

T_{OA} = total outbound tonnage originating above Welland

T_{IB}, T_{OB} similarly (for below Welland)

P_i, F_i specify the distribution of the fraction of inbound tonnage dropped off above Welland by a vessel which goes through Welland (F_i of the tonnage with probability P_i).

Then:

$$(1-P) + P\cdot[\sum_i P_i(1-F_i)] = T_{IB}/T_I$$

$$(1-P) + P\cdot(1-E(F)) = T_{IB}/T_I$$

$$P\cdot E(F) = 1 - \frac{T_{IB}}{T_I} = \frac{T_{IA}}{T_I}$$

$$P = \frac{T_{IA}}{T_I \cdot E(F)}$$

Hence, specification of the distribution of the fraction of a vessel's inbound tonnage which terminates above Welland (P_i, F_i) uniquely determines P, the proportion of vessels which go through Welland. This assumes that we know the fraction of inbound tonnage which terminates above (as opposed to below) Welland.

Required data inputs for the program are as follows:

1. For each port
   (a) port number
   (b) on which of the branches of the network it lies
   (c) annual inbound tonnage
   (d) annual outbound tonnage.
2. The frequence distribution (P_i, F_i) of the fraction of a vessel's inbound tonnage which terminates above Welland (given that the vessel goes through Welland).
3. Frequency distributions of
   (a) The number of stops for a vessel that does not go through Welland
   (b) The number of stops above Welland for a vessel that goes through Welland
   (c) The number of stops below Welland for a vessel that goes through Welland.
4. The probability of selecting Branch 1 as opposed to Branch 2.

In generating itineraries, the program must first randomly determine whether the vessel is to go through Welland. If, say, it is to go through Welland, then samples must be taken from distribtuions 3(b) and 3(c) above, respectively, to determine the number of stops above and below Welland.

The two segments of the itinerary are then generated independently. For each port, a determination is made randomly as to whether that port is to be in the subitinerary. If the number of ports selected is equal to the required number, this group of ports will go into the itinerary. If not, the selected group is saved in a table for possible later use. For example, suppose sampling from distribution 3(b) yields a value 3. This means there are to be three stops above Welland. The storage table is first consulted to see if a subitinerary of three ports above Welland is available from previous generation. If so, it will be used. If not, more subitineraries will be generated until one with three ports is produced. All those that are generated with fewer than three or more than three ports will be saved for possible later use. Note that in generating subitineraries for above Welland, either Branch 1 or Branch 2 must be selected, but not both.

Random selection of ports for subitineraries is based upon the frequency of calls by saltwater vessels at the various ports. Define the following FORTRAN variables:

NSA	relative total number of salt vessel calls above Welland
NSB	relative total number of salt vessel calls below Welland
NSVCAL(I)	relative total number of salt vessel calls at port I
SVTI(I)	relative total salt vessel tonnage inbound to port I
SVTO(I)	relative total salt vessel tonnage outbound from port I
EPAW	E (number of stops per itinerary above Welland | go through Welland)
EPBW	E (number of stops per itinerary below Welland | go through)
EPBW1	E (number of stops per itinerary | don't go through)
PCA(I)	P (choose port I | go through and branch for port I is chosen). I above Welland.

PCAF(I)	P (choose port I | go through). I above Welland.	
PCB(I)	P (choose port I | go through). I below Welland.	
PCB1(I)	P (choose port I | don't go through).	
PCBF(I)	P (choose port I). I below Welland.	
PCBR(I)	P (choose the branch on which port I lies | go through). I above Welland.	
PTW	P (go through Welland)	

Total number of calls and total tonnage are "relative" in that the absolute numbers are not important; only the ratios are used. The decision was made not to require NSVCAL( ) as input data. Rather, it is assumed that the number of calls at each port is proportional to the outbound tonnage. Thus, the program makes the substitution

$$NSVCAL(I) = SVTO(I).$$

If the user should desire to supply NSVCAL( ) as data, modification of the program to accommodate this change would be relatively simple. Calculation of the probabilities of selecting ports for itineraries is as follows:

$$NSA = \sum_{\substack{\text{ports above} \\ \text{Welland}}} NSVCAL(I)$$

$$NSB = \sum_{\substack{\text{ports below} \\ \text{Welland}}} NSVCAL(I)$$

PCAF(I) = NSVCAL(I)*EPAW/NSA

PCA(I) = PCAF(I)/PCBR(I)

PCB(I) = NSVCAL(I)*EPBW/NSB

PCB1(I) = NSVCAL(I)*EPBW1/NSB

PCBF(I) = PTW*PCB(I) + (1-PTW)*PCB1(I)

First, the decision is made as to whether the vessel will pass through Welland. If not, the ports (all below Welland) are selected according to the probabilities PCB1(I). If the vessel is to pass through Welland, Branch 1 or Branch 2 is selected, then ports are chosen according to probabilities PCA(I) and PCB(I).

After all of the ports have been selected for the itinerary, the next step is to determine the fractions of the vessel's tonnage to be loaded and unloaded at each port. Define additional FORTRAN variables:

PTAWI( )	Contains the distribution of the fraction of inbound tonnage that a vessel will unload above Welland given that the vessel passes through Welland
PTAWO( )	Similarly for outbound tonnage
AI	A random variate from PTAWI distribution
AO	A random variate from PTAWO distribution
PON(I)	Unadjusted fraction of vessel tonnage to be loaded at port I
POFF(I)	Unadjusted fraction of vessel tonnage to be unloaded at port I
PN(I)	Final fraction of vessel tonnage to be loaded at port I
PF(I)	Final fraction of vessel tonnage to be unloaded at port I

The calculations are carried out as follows for a vessel passing through Welland:

Let A be the set of ports on the itinerary above Welland.

Let B be the set of ports on the itinerary below Welland.

$$BI = 1-AI$$

$$BO = 1-AO$$

$$PON(I) = SVTO(I)/PCBF(I) \qquad I \in B$$

$$POFF(I) = SVTI(I)/PCBF(I) \qquad I \in B$$

$$TN = BO/\sum_{I \in B} PON(I)$$

$$TF = BI/\sum_{I \in B} POFF(I)$$

$$PN(I) = TN*PON(I) \qquad I \in B$$

$$PF(I) = TF*POFF(I) \qquad I \in B$$

$$PON(I) = SVTO(I)/PCAF(I) \qquad I \in A$$

$$POFF(I) = SVTI(I)/PCAF(I) \qquad I \in A$$

$$TN = AO/\sum_{I \in A} PON(I)$$

$$TF = AI/\sum_{I \in A} POFF(I)$$

$$PN(I) = TN*PON(I) \qquad I \in A$$

$$PF(I) = TF*POFF(I) \qquad I \in A.$$

Note that, in general, cargo is both loaded and unloaded during any stop on an itinerary. No port appears twice on any itinerary. For all but the western-most port on an itinerary, the decision must be made as to whether the stop should be made on the way in or on the way out. This determination is made by a very simple rule: If more is to be unloaded than loaded, the stop is made on the way in; otherwise, it is made on the way out. This rule assures that a vessel is never loaded over its capacity.

The thrust of all of the foregoing detailed calculations and explanations is that care must be taken in order to provide itineraries that reflect the observe movement patterns of saltwater vessels in the GL-SLS

system and at the same time provide the required mix of cargo-carrying capacity to move goods in and out of the ports. Following is a user manual which describes in detail the inputs and outputs associated with the itinerary generation program.

B. USER MANUAL

1. Introduction

All data inputs for this program are in fixed column formats. Several probability distributions are required, so that a few words about their input format are in order. The data are arranged as follows:

Card 1	Columns 1-8	Key word. This key word specifies which distribution follows.
Cards 2-n + 1	Columns 1-10	Right-justified. Value X.
	Columns 11-20	Right-justified 100 x the probability of observing the value X.
Card n + 1	Column 10	Zero.
	Column 20	Zero (signals the end of the data for this distribution).

Consider, for example, the following set of data:

```
KEXAMPLE
         7        20
        11        25
        12        10
        19        30
       176        15
         0         0
```

The random variable indicated by the key word KEXAMPLE is distributed such that it takes the value 7 with probability .20, 11 with probability .25 and so on. Note that the sum of the values in the second field must equal 100. Also, a key word may have fewer than 8 non-blank characters. The number of discrete values, n, for any distribution may vary between 1 and 100, inclusively.

2. Input Data Stream

All numbers should be right-justified in the indicated fields. If the indicated format is "I", no decimal point is allowed. If the format is "F", a decimal point may be punched anywhere in the field. The user should keep in mind that in all cases, both leading and trailing blanks are interpreted as zeroes. An "A" format signifies alphabetic data.

Card	Columns	Format	Description
1	1-10	I	The number of itineraries to be generated.
2	1-10	F	The probability of selecting Branch 1 given that the vessel is to pass through Welland.
3	1-5	A	PDATA: key word indicating that the port data cards are to follow.
	11-20	I	Number of ports.
	21-30	I	Number of the first port above Welland.
4	1-10	I	Port number. Ports must be numbered in the following sequence, uniquely and skipping no integers: (a) Branch 1 ports from west to east, (b) Branch 2 ports from west to east, (c) all other ports from west to east.
	11-20	F	Total inbound salt vessel tonnage for this port.

Card	Columns	Format	Description
	21-30	F	Total outbound salt vessel tonnage for this port.
	31-40	I	Branch number for this port. Zero if the port lies on neither Branch 1 nor Branch 2.
N + 4	1-8	A	Key word for probability distribution.
N + 5 on	1-10	I	Value X (Zero in last card).
	11-20	I	100 x probability of value X. (Zero in last card).

Each of the 4 distributions described below is entered sequentially in the preceding format.

Last	1-6	A	ENDATA. Key word signifying the end of the input data stream.

Probability distributions:

Key Word	Description of Distribution
NPBW	The number of ports below Welland on an itinerary in which the vessel passes through Welland.
NPBW1	The number of ports (all below Welland) on an itinerary in which the vessel does not pass through Welland.
NPAW	The number of ports above Welland on an itinerary in which the vessel passes through Welland.
PTAWI	The percentage of a vessel's inbound tonnage that it unloads above (as opposed to below) Welland, given that the vessel passes through Welland. The values are percentages, not fractions.

These distributions may be entered in any sequence.

Outputs

The primary output consists of the itineraries, written to file number 1. Also, the following information is written on file 6:

1. The calculated probability of passing through Welland.
2. For vessels passing through Welland, the expected fractions of inbound and outbound tonnage transferred above Welland.

For the generated itineraries:

3. Percent of vessels that passed through Welland.
4. Distributions of the number of ports of call
   - (a) above Welland for vessels that passed through
   - (b) below Welland for vessels that passed through
   - (c) for vessels that did not pass through
   - (d) for all itineraries.
5. The number of subitineraries generated.

CHAPTER 13. EDB PROCESSING PROGRAM

A. PROGRAM DESCRIPTION

This program is written in FORTRAN and is used to process the "experience data bank" (EDB) generated during an EDB simulation. In NETSIM II, a vessel confronted with a choice between two or more parallel routes to the same destination selects the route with the lower expected transit time. In order to establish the criteria for estimating such expected transit times, an EDB simulation run is made in which the parallel route selections are made randomly and resulting transit times are recorded along with certain usage parameters which describe the state of the route. The EDB processing program processes these records and arranges the usage parameters for each parallel segment with their associated vessel transit times so that they can be input directly to statistical analysis (such as a canned regression program).

Following is a user manual which describes the program's inputs and outputs in detail.

B. USER MANUAL

1. Input Data Stream

All values must be right-justified in the indicated fields. The user should keep in mind that all leading and trailing blanks are interpreted as zeroes.

Card Type	Columns	Description
1	1-2	The total number of parallel routes in the simulated system.
	4-5	Identification number of the highest numbered lock (same as HI.LOCK in NETSIM II).
	7-8	Identification number of the highest numbered reach (same as HI.REACH in NETSIM II).
	10-14	Total simulation time in minutes.
	16-17	A code set to 1 if the output is to be punched on cards, 0 otherwise.
	19-20	The input device number for the NETSIM II EDB records.
2	1-4	The identification number of the ending upstream facility (lock, reach, lake, etc.) on the route.
	6-9	The identification number of the ending downstream facility on the route.
		There will be one type 2 card for each parallel route in the system.

The EDB records from the NETSIM II EDB simulation must be supplied through the input device whose number is given in cc 19-20 of card type 1. This device could be a magnetic tape, card file, etc.

2. Outputs

The only program output consists of a series of records as follows:.

Card Type	Columns	Description
1	1-4	Vessel identification number.
	5-8	Vessel length in tens of feet.
	9-12	Vessel transit time through the route.

Card Type	Columns	Description
	13-14	Route number (in the order as input).
	15-16	Vessel's direction (1 = downstream, 2 = upstream).
	17-18	Number of entries on this record.
	19-20	1st usage parameter.
	21-22	2nd usage parameter.
	23-24	3rd usage parameter
	.	.
	.	.
	.	.
	79-80	31st usage parameter (if necessary).
2	1-2	32nd usage parameter (if necessary).
	3-4	33rd usage parameter (if necessary).
	.	.
	.	.
	.	.
	37-38	50th usage parameter (if necessary).

The program allows up to 50 parallel routes and 50 usage parameters per route. The usage parameters are as follows:

For a lock i) near queue size ii) far queue size

For a reach i) number of vessels in reach.

The usage parameters are listed in the order of facilities as input to NETSIM II in the parallel facilities table. The reason for having up to 50 parameters is that a route may contain many locks and reaches. If a route contains a lock, a reach and a lock, for example, there will be a total of five parameters given in the order of the facilities. That is, cc 19-20 in card type 1 will contain the near queue size for the first lock, cc 21-22 will contain the far queue size for the first lock, cc 23-24 will

contain the number of vessels in the reach, cc 25-26 will contain the near queue size for the second lock, etc.

APPENDIX D

PROGRAM IMPLEMENTATION

This appendix is offered as a rough guide to the programmer who must oversee the details of implementing the NETSIM II-PROSIM package. Specific machine considerations, core requirements and compile time are discussed in the following sections. Auxiliary input-output device requirements are very modest, as has been mentioned previously in this publication. A system with a card reader and two or three tape drives should serve the purpose. No discussion is given of execution time since it is so variable with system characteristics, run parameters, congestion, etc. Let is simply be said that for a large system, computer run time can be "considerable."

A. MACHINE FORMAT

The two main programs in the package, NETSIM II and PROSIM, are written in SIMSCRIPT II.5. Thus, the most immediate consideration in selecting a computer is whether a SIMSCRIPT II.5 compiler is available for that computer. If a different version of SIMSCRIPT is available, some program modification may be required.

The internal data representation within the machine is also to be considered. The programs were developed for the IBM System 360 or 370 which use words consisting of eight-bit bytes. This format has affected the data packing within the programs. For example, variables that are packed into one-quarter of a word cannot exceed a value of 127. Those that are packed into one-half of a word cannot exceed 32,767. If the machine to be used has smaller quarter-words or if quarter-words cannot be addressed, the data packing (in the preambles of the two programs) will have to be altered.

The auxiliary programs in the simulation package are written in IBM level G FORTRAN. One difficulty that could arise, even with other level G compilers, is that the programs may reference subroutines that are resident in the PSU FORTRAN library but are not found in other FORTRAN libraries. For example, the itinerary generation program calls a function RAND(X) which returns pseudo-random numbers. If such a routine is not supplied by the system, it will have to be programmed and compiled with the itinerary generation program.

B. CORE REQUIREMENTS

Core memory requirements in both NETSIM II and PROSIM vary according to the size of the system being simulated. Following are formulas which estimate the core requirements on an IBM OS/370 system for each of the programs. Estimates are given in bytes.

1. NETSIM II

$$\text{Bytes} = 126{,}000 + 220A + 4B + 64C + 124D + 216E + 48F + 100G + 50H + 8AB + 2AF + F^2 + 4A^2B$$

where

A = number of ports

B = number of commodities

C = number of vessels (saltwater and bulk)

D = number of lakes

E = number of locks

F = number of nodes

G = number of reaches

H = maximum number of saltwater vessels in the system at any one time.

As an example, a system with 22 ports, 12 commodities, 1000 total vessels, 5 lakes, 10 locks, 50 nodes, 15 reaches and a maximum of 200 saltwater vessels in the system at once would require about 241,000 bytes.

2. PROSIM

Bytes = 211,000 + 344A + 20C + 40D + 236E + 52G

where the variables are defined as above. A system of the same size as in the example above would require 242,000 bytes.

C. COMPILATION TIME

Compile times for NETSIM II and PROSIM on an IBM 370/165 are as follows:

	CPU seconds	Elapsed seconds
NETSIM II	90	350
PROSIM	130	360

Of course these times, especially the elapsed times, can vary somewhat from one compilation to another.

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